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COMAND — A FORTRAN PROGRAM FOR
SIMPLIFIED COMPOSITE ANALYSIS AND
DESIGN

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## Garret N. Vanderplaats

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#### INTRODUCTION

Early evaluation of composite materials in aerospace structures requires an efficient means of structural sizing for a given application. It is seldom possible to provide simple stress limits as is customary when designing with conventional isotropic materials, since failure of composites is dependent not only on the properties and orientations of the individual plys, but on the nature of the loading as well. Furthermore, by taking advantage of the ply orthotropicity, the designer is free (within certain limits) to actually design the structural material through the proper choice of ply thicknesses and orientations.

COMAND is one of several programs being developed in the Advanced Vehicle
Concepts Branch of Ames Research Center to provide a general and consistent
approach to structural analysis and design. This program is for the analysis
and design of a multilayered composite subject to inplane loads. The principal
method of analysis and the failure criterion considered here are those used
by Schmit and Farshi (Ref. 1). The optimization algorithm is the method of
feasible directions using program CONMIN, which is described in Reference 2.

COMAND is intended to provide first level design information for membrane
structural behavior. Another program under development includes more general
analysis, loading conditions, and failure criterion.\*

<sup>\*</sup>Program COMPOS by J. Mullen, Advanced Vehicle Concepts Branch, Ames Research Center.

The analysis and design capabilities and the basic assumptions of the program are presented in Section I. Section II describes the required input to the program and several examples of the results are presented in Section III. Possible future efforts in composite analysis and design are identified in Section IV. The principle equations used in the analysis are presented in Appendix A. Appendix B is a complete program listing.

#### SECTION I

#### ASSUMPTIONS AND RESTRICTIONS

Program COMAND can be used to analyze a given composite panel in which the ply thicknesses are prescribed, or to design the ply thicknesses to satisfy strain and stiffness limitations. Ply orientation angles are prescribed, and are not design variables. Typical loading conditions and ply orientations are shown in Figures 1 and 2, respectively.

The composite analysis and design is based on the following assumptions and restrictions.

- The panel is subjected to in-plane loads NX, NY and NYX only.
   Bending and out-of-plane shear loads are not considered. Multiple loading conditions are considered and up to 10 independent loading conditions are allowed.
- 2. The composite is said to fail when the longitudinal, transverse or shear strain in any single ply exceeds a specified limit in the longitudinal, transverse or shear direction, respectively.
- 3. The composite is said to fail if the stiffness in the structural X, Y or XY direction is less than a specified lower limit.

- 4. The individual ply thicknesses are designed to give minimum total panel thickness. Ply thicknesses are treated as continuous variables and several plys may be required to be of equal thickness.
- 5. All plys are of the same material with the same elastic properties and strain limitations. Ply elastic properties (and therefore, those of the composite) are assumed to be the same in tension and compression.
- 6. Ply properties are required as program input. Micromechanics analysis is not performed in the program.
- 7. The composite is assumed to be symmetric about the midplane so that no bending-membrane coupling exists.
- 8. The composite need not be balanced. That is, a ply with +45 degrees fiber orientation need not be balanced with another ply of -45 degrees orientation. Up to 18 different ply orientations are permitted, allowing for design of composites with ply angles at 10 degree intervals. Ply fiber orientation angles are prescribed and are not design variables.
- Temperature effects and temperature loading are not considered, except that the material properties and strain limits must be consistent with the design temperature.

#### SECTION II

#### PROGRAM INPUT

All program input is listed here. The variables and their definitions are presented first, followed by data organization. No units are provided

for the variables. It is required that all units be consistent. That is (for example), if loads are in newtons and thicknesses in meters, moduli must be given in newtons per square meter, strains in meters/meter and stiffness in newtons/meter.

## Variables:

TITLE(15) Anything may be given as a title.

NCALC Calculation control. If NCALC=0, total composite thickness (weight) is minimized. If NCALC.NE.O. the given composite is analyzed only.

NPLY Number of plys. Up to 18 plys are allowed.

NDV Number of design variables. This is the number of ply thicknesses which are allowed to change independently in the optimization process or the number of different thicknesses prescribed for analysis. 1.LE.NDV.LE.NPLY

NLC Number of loading conditions. Up to 5 loading conditions are allowed.

IPRINT Print control for the optimization program, CONMIN. IPRINT = 0
gives no print during the optimization. IPRINT = 1 to IPRINT = 4
provide increasing degrees of output during optimization.

IPRINT = 2 is usually desirable.

LNK(NPLY) Design variable linking. LNK(I) gives variable number (ply thickness) associated with the ITH ply. For example, in a four ply problem (NPLY = 4),  $LNK^{T}$  = (1, 2, 2, 3) will impose the requirement that plys 2 and 3 are of the same thickness. In this case NDV = 3.

X(NDV) Initial thickness of the design variables (IE.  $X^T = .05$ , .03, .04). If NCALC.NE.O., the composite is analyzed for ply thicknesses defined in X and linked according to LNK. If J = LNK(I), the thickness of the ITH ply is stored in X(J).

VLB(NDV)

Lower bounds on the design variables. VLB(I).GE.O, I = 1,NDV.

It is usually desirable to set at least one VLB(I) = 1.0E-10 if
lower bounds of zero are desired, in order to prevent the optimization
program from attempting to analyze a panel of zero thickness. If

NCALC.NE.O. VLB(I) = 0, I = 1, NDV may be input.

THN(NPLY) Ply orientations in degrees, referenced to the structural X-axis.

THN(I) = Ply orientation of the ITH ply.

EL Ply longitudinal modulus.

ET Ply transverse modulus.

GLT Plv shear modulus.

PRLT Ply major Poisson's ratio (ply transverse Poisson's ratio, PRTL, is calculated internally).

EPLC Ply longitudinal compressive strain limit (negative number).

EPLT Ply longitudinal tensile strain limit (positive number).

EPTT Ply transverse tensile strain limit (positive number).

GMLT Ply maximum shear strain limit (positive number).

AllL Lower bound on composite stiffness in the structural X-DIRECTION.

A22L Lower bound on composite stiffness in the structural Y-DIRECTION.

A66L Lower bound on composite shear stiffness.

PN(3, NLC) Loads, column I corresponds to loading condition I, I = 1, NLC.

Row J corresponds to load NX, NY and NXY for J = 1, 2 and 3,

respectively of load condition I.

## Data Organization:

No. of Cards	Information	Format
1	Title - Anything may be given here	15 <b>A</b> 4
1	NCALC, NPLY, NDV, NLC, IPRINT	515
1	LNK(I), I=1, NPLY	1515
1-3	X(I), I=1,NDV	8F10.2
1-3	VLB(I),I=1,NDV (Blank card(s) if NCALC.NE.0)	8F10.2
.1 <b>-3</b>	THN(I), I=1, NPLY	8F10.2
1	EL, ET, GLT, FRLT	4F10.2
1	EPLC, EPLT, EPTC, EPTT, GMLT, AllL, A22L, A66L	8F10.2
NLC	PN(J,I),J=1,3 (One card per loading condition)	3F10.2
	Begin with next set of data. Program terminates	
	if 2 blank cards are read here.	

This information is duplicated in Table 1, along with a data form for convenient reference.

#### SECTION III

#### **EXAMPLES**

Several examples are presented here to aid the user in making the program operational and to provide some insight into design using composite materials. All examples are for a high strength graphite-epoxy composite.

Typical ply unidirectional properties are listed in Table 2 for a fiber volume fraction of 0.6. The table is reproduced directly from Reference 3. Note that the ultimate strain limits are not specified for longitudinal and transverse strain or for shear. However, reasonable values are readily

obtained by analyzing a single ply of unit thickness, subject to a set of loads which are equal to the ultimate stresses. For example, given a longitudinal load of 180,000 lb/in. the resulting longitudinal strain will be ultimate strain. Therefore, a single ply composite is analyzed for the following load conditions:

Load Condition	<u>NX</u>	NY	NXY
1	180000.	0.	0.
3	0.	-30000.	0.
2	0.	8000.	0.
4	0.	0.	12000.

Note that a negative NX load is not imposed because the ultimate longitudinal compressive stress is the same in magnitude as the tensile stress. Therefore, the ultimate strains are also equal in magnitude (but opposite in sign).

The program input variables are now:

THN(1) = 0.

TITLE:	Determination of strains - G/E composite.
NCALC = 1	Analysis
NPLY = 1	One ply.
NDV = 1	One thickness.
NLC = 4	Four load conditions.
IPRINT = 0	Not used for analysis.
LNK(1) = 1	Ply thickness = X(1).
X(1) = 1.0	Composite thickness.
VLB(1) = 0.	Not used for analysis.

Zero degree ply orientation.

EL = 21,000,000 Longitudinal modulus.

ET = 1,700,000 Transverse modulus

GLT = 650,000 Shear modulus.

PRLT = 0.21 Major Poisson's ratio.

EPLT = EPLC = EPTC = GMLT = 0 - Strain limits set to zero since they are not known.

AllL = A22L = A66L = 0 Not meaningful here

PN(I,J) - Loads, given above.

The input data is listed in Table 3 with the corresponding output in Figure 3. The ultimate strains are now the actual ply strains in the direction of the applied load for the corresponding loading condition. For example, since load condition 1 is the ultimate longitudinal stress, the longitudinal strain, EPL, under this load condition is also ultimate. That is:

EPLT = 0.00857 (table 2 gives 0.00870)

Similarly,

EPLC = -0.00857

EPTC = -0.0176

EPTT = 0.00471 (table 2 gives 0.00475)

GMLT = 0.0185

These are now the limit strains to be used in design.

# Example 1 - Quasi-isotropic composite

In order to draw a comparison between graphite epoxy composites and the familiar aluminum materials, a simple case is first considered in which plys are oriented at 15 degree intervals (NPLY = 12) and subject to a single

unidirectional load, NX = 20,000 lb/in. (NY=NXY=0). All plys are required to be of the same thickness so that NDV=1 and LNK(I)=1, I,NPLY. The total thickness is minimized. No minimum stiffness limits are imposed, so that A11L=A22L=A66? =0. Lower bounds on the thicknesses are arbitrarily set to 0.00001 in. Initial ply thickness is prescribed as 0.05 in. The input data is listed in Table 4, where the print control for the optimization program, CONMIN, is taken as IPRINT = 2. The program output is listed in Figure 4. The optimum composite thickness is 0.525 inches. The design is constrained by the transverse strain limit in the 90 degree direction (ply number 12). The average stress in the structural X-direction (direction of load) in the composite is 38,000 PSI. Note that this is significantly less than the ultimate stress of 60,000 PSI for a typical aluminum alloy. However, the density of the composite is 0.056 lb/in.\*\*3 as compared to 0.101 lb/in.\*\*3 for aluminum. Therefore, the relative weight of graphite epoxy as compared to aluminum for this example is 0.056\*60000/(0.101\*38000 = 0.875 giving a 12.5 percent weight savings.

Note that even though the 90 degree ply has failed, some additional load may be carried before all plys fail. Therefore, the failure stress predicted here may be considered analogous to the limit stress, with the ultimate stress being (usually) somewhat higher.

#### Example 2 - (0. +45, 90) composite design

Due to practical considerations, it is improbable that many different ply orientations will be used in most structures. In this example, the composite is required to be balanced so that the thicknesses of the 445 and -45 degree plys are the same. Then there are three independent design

variables (NDV = 3) and the ply thickness linking vector becomes  $LNK^{T} = (1, 2, 2, 3)$ . The ply orientation vector is  $THN^{T} = (0., 45., -45., 90.)$ . A minimum stiffness of 500,000. lb/in. is required in the structural X-direction. The composite is required to support the following four independent loading conditions:

Load Condition	NX	<u>NY</u>	NXY
1	20000.	0.	0.
2	15000.	-15000.	5000.
3	-15000.	10000.	10000.
4	0.	0.	20000.

The input data is listed in Table 5 and the corresponding output in Fig. 5. The print control for CONMIN is set to IPRINT = 0 in this example and in example 3 for brevity. The optimum composite thickness is 0.578 inches. The active constraints are transverse strain limits and are identified by safety factors of unity in Fig. 5 (3 constraints are active).

# Example 3 - $(0. \pm 30, \pm 60, 90)$ composite design.

This composite is designed subject to the same constraints and loading conditions as example 2. the only difference is the number of plys and their orientations. The composite is again required to be balanced. In this case, NDV = 4, NPLY = 6,  $LNK^T$  = (1, 2, 2, 3, 3, 4), and  $THN^T$  = 0., 30., -30., 60., -60., 90.). The input data and output are listed in Table 6 and Fig. 6, respectively. The optimum composite thickness is 0.532 inches and there are six active strain limit constraints as seen from Fig. 6. Note that although the number of plys and their orientations are different from example 2, the total composite thickness is reduced by less than ten percent.

An additional exercise of interest is to eliminate plys which comprise a small percentage of the total thickness, and solve the optimization problem again. For example, a composite made up of ±30 and ±60 degree ply orientations results in an optimum thickness of 0.526 inches. It is instructive to design the 12 ply composite of example 1 subject to this same set of loads, but allowing for different ply thicknesses (require that the composite be balanced for consistency with examples 2 and 3). The resulting thickness is 0.588 inches. Solution of this case is left as an exercise.

## Example 4 - Limit stress vs. ply thickness distribution

In order to assess the applicability of this program to preliminary composite design, results obtained using COMAND are compared here with design curves for a (0, ±45, 90) composite subjected to uniaxial tension, compression and shear loading (applied separately). Figures 7-10 are reproduced from Reference 3. A composite with various relative ply thicknesses was analyzed under these separate loading conditions. No stiffness constraints were imposed and the lowest factor of safety was found for all strain failure criterion. The calculated stress was then multiplied by this factor to give the failure (limit) stress. The results are plotted on Figures 7-10 for 25 and 50 percent zero degree plys. Figure 10 compares the extensional modulus, E<sub>x</sub>.

The results indicate reasonable comparison for compressive stress, shear stress and extensional modulus. However, considerable discrepancy is found in comparing tensile stress limits. This is because the composite is constrained by transverse strain limits on the 90 degree plys. In Reference 3, one or more plys are allowed to fail without assuming composite failure.

When a single ply fails, this ply is assumed to carry no load. The composite is said to fail only when all plys fail individually. This again demonstrates the difference between the limit stress calculated here and the ultimate stress presented in Reference 3. The difference in results between these two assumptions is usually reduced when multiple sets of combined loadings (practical design situations) are considered.

#### SECTION IV

#### DISCUSSION

A short program has been presented by which first estimates are readily obtained for design requirements of composite structures. The program is easily used and requires minimal execution time. Because the failure criterion are extremely load dependent, some judgement is necessary in choosing permissible ply orientations, so that the existence of a given ply orientation does not prevent attainment of an optimum design. This problem is much less prevalent under multiple loading conditions. However, it does suggest that development of an optimization algorithm capable of completely eliminating plys may be fruitful.

For the results to be meaningful, it is important that this program be applied only to structures satisfying (at least approximately) the restrictions imposed in Section I. Of particular importance are the restrictions of inplane loading and composite symmetry about the midplane.

Recognizing the complexities of composite analysis and design as well as the benefits to be gained through the use of these materials, future development work in this area appears warranted.\*\*

<sup>\*\*</sup>Several of the topics identified here are currently being included in the COMPOS program by J. Mullen at ARC.

These efforts should include more complex loading such as bending, out of plane shear, and temperature loads on nonsymmetric composites. This necessarily requires the inclusion of more sophisticated analysis techniques and failure criterion. Panel buckling under various force and displacement boundary conditions is also an area of interest because, with increased composite strengths, stiffness requirements become increasingly important, since the probability of failure in this mode is increased with reduced plate thicknesses. Additionally, analysis and design of composites made up of plys of differing elastic properties is a needed and straight forward extension. This will provide the capability of selective reinforcement of conventional isotropic materials as well as use of various combinations of advanced materials. Finally, these capabilities should be incorporated into a general finite element analysis and design program for application to large scale structures of practical interest.

#### APPENDIX A

#### COMPOSITE ANALYSIS AND DESIGN EQUATIONS

## Analysis Equations

The equations used for analysis and design are presented here. These equations are consistant with the assumptions listed in Section I.

Equation numbers beginning with the letter A are consistant with Reference 1.

The analysis is based on the ply materials properties  $E_L$ ,  $E_T$ ,  $G_{LT}$ ,  $v_{LT}$  and  $v_{TL}$ , ply thicknesses,  $t_i$ , and orientations,  $\theta_i$ .

The force deformation equations for the kth load condition are;

$$\{N\}_{k} = [A] \{\epsilon\}_{k}$$
 [A1]

where

$$\left\{ N \right\}_{k} = \left\{ \begin{array}{l} N_{xk} \\ N_{yk} \\ N_{xyk} \end{array} \right\} \qquad \left\{ \varepsilon \right\}_{k} = \left\{ \begin{array}{l} \varepsilon_{xk} \\ \varepsilon_{yk} \\ \gamma_{xyk} \end{array} \right\} = \left\{ \begin{array}{l} \frac{\partial u_{k}}{\partial x} \\ \frac{\partial v_{k}}{\partial y} \\ \frac{\partial v_{k}}{\partial x} + \frac{\partial u_{k}}{\partial y} \end{array} \right\}$$

 $\{N\}_k$  is the vector of applied in-plane loads referenced to the structural x-axis and  $\{\epsilon\}_k$  is the corresponding strain state. u and v are the displacements in the coordinate x and y directions, respectively.

$$A_{rs} = \sum_{i=1}^{NPLY} (C_{rs}^{i})t_{i}$$
  $r,s = 1,2,6$  [A2]

where  $t_i$  is the thickness of the plys oriented at angle  $\theta_i$  with respect to the structural x-axis. Coefficients  $(C_{rs}^i)_i$  are defined in terms of  $\theta_i$  and

and the ply elastic constants as

$$(c_{11}^{i})_{i} = (c_{11})_{i} \quad \ell_{i}^{i} + 2(c_{12})_{i} \quad \ell_{i}^{2} \quad m_{i}^{2}$$

$$+ (c_{22})_{i} \quad m_{i}^{i} + 4(c_{66})_{i} \quad m_{i}^{2} \quad \ell_{i}^{2}$$
[A3]

$$(c_{12}^{\prime})_{i} = (c_{11})_{i} \ell_{i}^{2} m_{i}^{2} + (c_{12})_{i} (\ell_{i}^{4} + m_{i}^{4}) + (c_{22})_{i} \ell_{i}^{2} m_{i}^{2} - 4(c_{66})_{i} \ell_{i}^{2} m_{i}^{2}$$
[A4]

$$(c_{16}^{\prime})_{i} = (c_{11})_{i} \ell_{i}^{3} m_{i} + (c_{12})_{i} (m_{i}^{3} \ell_{i} - \ell_{i}^{3} m_{i})$$

$$- (c_{22})_{i} m_{i}^{3} \ell_{i} + 2(c_{66})_{i} (m_{i}^{3} \ell_{i} - m_{i}^{3} \ell_{i}^{3})$$
[A5]

$$(c_{22}^{\dagger})_{i} = (c_{11})_{i} m_{i}^{4} + 2(c_{12})_{i} m_{i}^{2} \ell_{i}^{2}$$

$$+ (c_{22})_{i} \ell_{i}^{4} + 4(c_{66})_{i} m_{i}^{2} \ell_{i}^{2}$$
[A6]

$$(c_{26}^{\dagger})_{i} = (c_{11})_{i} m_{i}^{3} \ell_{i} + (c_{12})_{i} (\ell_{i}^{3} m_{i} - m_{i}^{3} \ell_{i})$$

$$- (c_{22})_{i} m_{i} \ell_{i}^{3} + 2(c_{66})_{i} (m_{i} \ell_{i}^{3} - m_{i}^{3} \ell_{i})$$
[A7]

$$(c_{66}^{\dagger})_{\underline{i}} = (c_{11})_{\underline{i}} m_{\underline{i}}^{2} \ell_{\underline{i}}^{2} - 2(c_{12})_{\underline{i}} m_{\underline{i}}^{2} \ell_{\underline{i}}^{2}$$

$$+ (c_{22})_{\underline{i}} m_{\underline{i}}^{2} \ell_{\underline{i}}^{2} + (c_{66})_{\underline{i}} (\ell_{\underline{i}}^{2} - m_{\underline{i}}^{2})^{2}$$
[A8]

where

$$\ell_{i} = \cos \theta_{i}$$
  $m_{i} = \sin \theta_{i}$  [A9]

$$(c_{11})_{i} = \frac{E_{Li}}{(1-v_{LTi}v_{TLi})}$$
 [A10]

$$(c_{12})_{i} = \frac{v_{TLi} E_{Li}}{(1 - v_{LTi} v_{TLi})} = \frac{v_{LTi} E_{Ti}}{(1 - v_{LTi} v_{TLi})}$$
 [A11]

$$(c_{22})_i = \frac{E_{Ti}}{(1 - v_{I,Ti} v_{TI,i})}$$
 [A12]

$$(c_{66})_i = G_{LTi}$$
 [A13]

Note that the subscript i is not required on equations [A10]-[A13] since the elastic properties are assumed the same for all plys. The subscript is retained here for consistency.

Given the loads  ${\rm \{N\}}_k$ , the membrane strains are obtained from equation [A1] as

$$\{\epsilon\}_{k} = [A]^{-1} \{N\}_{k}$$

Finally the strains in the ith ply (kth load condition) are determined from

$$\varepsilon_{1ik} = \ell_{i}^{2} \varepsilon_{xk} + m_{i}^{2} \varepsilon_{yk} + m_{i}\ell_{i} \gamma_{xyk}$$

$$\varepsilon_{zik} = m_{i}^{2} \varepsilon_{xk} + \ell_{i}^{2} \varepsilon_{yk} - m_{i}\ell_{i} \gamma_{xyk}$$

$$\gamma_{12ik} = -2m_{i}\ell_{i}\varepsilon_{xk} + 2m_{i}\ell_{i}\varepsilon_{yk} + (\ell_{i}^{2} - m_{i}^{2}) \gamma_{xyk}$$
[A14]

If the stresses in the ith ply are required, these may be obtained from the orthotropic elastic stress-strain relationships to be

$$\sigma_{1ik} = (c_{11})_{i} \epsilon_{1ik} + (c_{12})_{i} \epsilon_{2ik}$$

$$\sigma_{2ik} = (c_{12})_{i} \epsilon_{1ik} + (c_{22})_{i} \epsilon_{2ik}$$

$$\tau_{12ik} = (c_{66})_{i} \gamma_{12ik}$$
[15]

### Design Equations

The design objective is to minimize the total composite thickness (and therefore weight);

Minimize 
$$W = \sum_{i=1}^{NPLY} t_i$$

Constraints on the design include limit ply strains and lower bounds on stiffness.

The limit strains imposed on the individual plys are expressed as constraint functions as follows:

$$\begin{aligned} & G_{1ik} = \frac{\varepsilon_{1ik}}{EPLC} - 1. & \leq 0 & i = 1, \text{ NPIY, } k = 1, \text{ NLC} \\ & G_{2ik} = \frac{\varepsilon_{1ik}}{EPLT} - 1. & \leq 0 & i = 1, \text{ NPLY, } k = 1, \text{ NLC} \\ & G_{3ik} = \frac{\varepsilon_{2ik}}{EPTC} - 1. & \leq 0 & f = 1, \text{ NPLY, } k = 1, \text{ NLC} \\ & G_{4ik} = \frac{\varepsilon_{2ik}}{EPTT} - 1. & \leq 0 & i = 1, \text{ NPLY, } k = 1, \text{ NLC} \\ & G_{5ik} = \frac{|\gamma_{12ik}|}{GMLT} - 1. & \leq 0 & i = 1, \text{ NPLY, } k = 1, \text{ NLC} \end{aligned}$$

where subscript i denotes ply number and subscript k denotes load condition.

Lower bounds on stiffness are expressed as constraint functions;

$$\bar{G}_1 = 1. - A(1,1)/AllL \le 0.$$

$$\overline{G}_{2} = 1. - A(2,2)/A22L \le 0.$$

$$\bar{G}_3 = 1. - A(3,3)/A66L \le 0.$$

Constraints on strains are nonlinear functions of the design variables,  $t_1$ . The values of these constraints are stored in vector G, (five values per ply, one ply after another) for each load condition in sequence. Constraints  $\bar{G}_1$ ,  $\bar{G}_2$  and  $\bar{G}_3$  on stiffness are linear functions of the design variables. The values of these constraints are stored after constraints on strains in vector G.

There are 5\*NPLY\*NLC nonlinear constraints and three linear constraints on the optimization problem. Program "CONMIN" defines a nonlinear constraint as "active" if its value is greater than or equal to a specified value CT (a small negative number). Linear constraints are "active" if their value equals or exceeds a value of CTL. If a given constraint is active the analytic gradient of this constraint with respect to the independent design variables, t<sub>1</sub>, must be supplied. This information is obtained by direct differentiation of the constraint functions and is readily calculated using the equations of analysis.

# APPENDIX B

# PROTRAM LISTING

A complete FORTRAN listing of program "COMAND" is given here.

In addition, program "CONMIN" is required and this program is described in reference 2. The general program organization is shown in block diagram form in figure 11.

PRICEIAN CURNUM - A FORTRAN PROGRAM FOR COMPOSITE ANALYSIS   10   C   N. C   MANUSCO PLONG SIGNATURE   130   C   C   C   C   C   C   C   C   C		COMPOSITE AMALYSIS AND DESIGN PROGRAM - COMAND	JULY, 1974		COMPOSITE AMALYSIS AND DESIGN PROGRAM - COMAND	JULY, 1974
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COMPIN - 2007 C REF, 1 - VARDERPLAATS, G. N., SCUHAND - A FORTRAN PROGRAM FOR 200 C PEF, 1 - VARDERPLAATS, G. N., SCUHAND - A FORTRAN PROGRAM FOR 200 C SIRPLIFIED COMPOSITE AMALYSIS AND DESIVES, NASA IM X-**,***, 240 C SIRPLIFIED COMPOSITE AMALYSIS AND DESIVES, NASA IM X-**,***, 240 C ALG. 1975. C REF, 2 - SCHHIT, L. A., AND FARSHI, 9.1 SUPTINUM LAMINATE DESIGN 250 C REF, 2 - SCHHIT, L. A., AND FARSHI, 9.1 SUPTINUM LAMINATE DESIGN 250 C REF, 2 - SCHHIT, L. A., AND FARSHI, 9.1 SUPTINUM LAMINATE DESIGN 250 C REF, 2 - SCHHIT, L. A., AND FARSHI, 9.1 SUPTINUM LAMINATE DESIGN 250 C REF, 2 - SCHHIT, L. A., AND FARSHI, 9.1 SUPTINUM LAMINATE DESIGN 250 C REGAL STRAIN AND STIFFRESS. INT. J., FAR NUMERICAL METHODS 270 C REGAL STRAIN AND STIFFRESS. INT. J., FAR NUMERICAL METHODS 270 C REGAL STRAIN AND STIFFRESS. INT. J., FAR NUMERICAL METHODS 270 C REGAL STRAIN AND STIFFRESS. INT. J., FAR NUMERICAL METHODS 270 C REGAL STRAIN AND STIFFRESS. INT. J., FAR NUMERICAL METHODS 270 C REFORMANCE AND COMPINE AND STRAIN AND STIFFRESS. AND STRAIN AND STIFFRESS. AND STRAIN AND STIFFRESS. AND STRAIN AND AND STRAIN AND STIFFRESS. AND STRAIN AND AND STRAIN AND STIFFRESS. AND STRAIN AND AND AND AND AND STRAIN AND STIFFRESS. INT. J. STRAIN AND STIFFRESS. INT. J. STRAIN AND STIFFRESS. INT. AND STIFFRESS. INT. AND STRAIN AND STIFFRESS. INT. AND STIFFRESS. INT. AND STRAIN AND STIFFRESS. THAT AND STRAIN AND STIFFRESS.	Ç					
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C REF. 1 - VARDERPLAATS, G. N., SCOMAND - A PORTRAN PROBLAM FOR 230 C SIRPLIFIED COMPOSITE MAINTSIS AND DESIGNS, NASA TH X=+0,*000, 240 PROBLEM FROM 11-21-11-11-11-11-11-11-11-11-11-11-11-1	Ç			· ·		
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C IN ENGINEERING, VOL. 7, NO. 4, PP. 519-536, 1973.  C EQUATION NUMBERS LISTED IN THIS POLOGRAM ARE FROM THE ABOVE 200 DG 30 I=1, NCC.  PEFERLACE.  C REF. 3 - COMMIN - A FORTRAM PRIGRAM FOM CONSTRAINED FUNCTION 310 IO NEARL (1,210) (PN(4,11),1-13) 810  C REF. 3 - COMMIN - A FORTRAM PRIGRAM FOM CONSTRAINED FUNCTION 310 IO NEARL (1,210) (PN(4,11),1-13) 810  C MINIMIZATIONT USER'S NAMUAL, BY G. N. VANDERPLAATS, 320 C NCOM = NUMBER OF CONSTRAINES. 820  C MASA IN 2-62,222 AUGUST, 1973. 330 NCC.  C THIS PRUGRAM USES COMMIN VERSION II, DATED JULY, 1975. 340  C ASSUMPTILMS: 330 NCC.  C BUUNCARY (CONSTRAINES) BURNEY CONSTRAINED (1,000) NK, NY AND NXY. 350  C ALL PLYS HAVE SAME HATERIAL PROPERTIES AND FAILURE STRAINS. 370 ISC(M1)=1  C FAILURE CHITERION ARE MALPY LUNGITUONAL TRANSVERSE AND SHEAR 360  C STRAINS, AND STIFFMESS LIMITS ON A11, A22 AND A66. 300 ISC(M1)=1  C CONSTURBED. 400  C MEMBRANE LCAUS DILY - MULTIPLE LOADING CUNDITIONS ARE 410 IF I>22.  C CONSTURBED. 400  C STREITS ABOUT HIJPLAME IS ASSUMED. 400  C STHETRY ABOUT HIJPLAME IS ASSUMED. 400  C NCALC * CALCULATION CUNTROL  C CONSTURBED. 400  C NCALC * CALCULATION CUNTROL  C NEAR CALCULATION CUNTROL  C NCALC * CALCULATION CUNTROL  C NEAR CALCULATION CUNTR	Ļ	KEL 5 - 200411 for the back but 1 23 304 1100 Culturals near 1		•		
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C ALL PLYS HAVE SAME MATERIAL PROPERTIES AND FAILURE STRAIMS. 370   ISC(M1)=1   870   C FAILURE CRITERION ARE MAX PLY LUNGITUDINAL. TRANSVERSE AND SHEAR 380   ISC(M1+1)=1   890   C STRAINS, AND STIFFHESS LIMITS OR ALL AZZ AND A66. 390   ISC(M1+2)=1   890   C WHEN ANY ONE PLY FAILS, THIS IS DEFINED AS COMPOSITE FAILURE. 400   IF (ALLLA,T.1.0E-1D) NCUN-HCCUN+1   900   C MEMBRANE LCAUS ONLY - HULTIPLE LOADING CONDITIONS ARE 410   IF (AZCL,T.1.0E-1D) NCUN-HCCUN+1   910   C CONSIDERED. 420   IF (AZCL,T.1.0E-1D) NCUN-HCCUN+1   920   C SYMPTETY ABOUT MISPLANE IS ASSUMED. 430   C PAINT INPUT INPURRATION. 930   C COMPOSITE NEED NOT BE BALANCED. 450   IF (MACL,C.D.) WRITE(62,0D) WRITE(62,0D)   960   C NCALC = CALCULATION CONTROL 460   WRITE (62,2C)   WRITE(62,47D)   960   C NCALC = CALCULATION CONTROL 460   WRITE (62,2C)   WRITE (62,2C)   960   C NCALC = CALCULATION CONTROL 460   WRITE (62,2C)   WRITE (62,2C)   970   C NCALC = NALAYSIS ONLY   WRITE (62,2C)   WRITE (62,2	· ·			70		•
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C   C   C   C   C   C   C   C   C   C				•		
C NCALC = CALCULATION CONTROL 460 WALLE (6,220) C 0: DC DPTHIZATION	<u>,</u>	COURCELLE MEED MOT BE BALANCED.				
C D: DE LPTIHIZATION 470 MAIT (6/150) TITLE 970 C NE.D: D' AMALTSIS DNLY 980 C NELD: D' AMALTSIS DNLY ASSUMED. 490 WAITE (6/250) PLLY-PALC 980 C NPLY = NI-POEL DF PLYS. SYNHETRY ASSUMED. 490 WAITE (6/254) EL-ET-GELT-PRET.	ž	NCALC & CARCULATION FONTON				
C HELD: D'AMAEYSIS DALY C HPLY = NIPBER OF PLYS. SYNHETRY ASSUMED. 480 490 490 490 490 491 490 490 491 490 490 491 490 490 490 491 490 490 490 490 490 490 490 490 490 490	č					
C HPLY - NIPOLK OF PLYS. SYNHETHY ASSUMED. 490 NP.IIE 10.244) ELPET.GLT.PRIT. 990	÷					
	ř					
	č	PHOGRAM TERMINATED IF MPLY=0.				1000

# REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

0 30   1- -NotT   1010   00   00   00   00   00   00		COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND	JULY, 1974		COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMMIND	JULY, 1974
Online   10   10   10   10   10   10   10   1		The same of the sa	1010	40	WRITE (0,260) I,TN(I),PCI	
The control of the				Č	TOTAL THICKNESS.	
Will	5U			•		
##ITE 10.9001 CILLIANZES/SOBL 1000				C		
RITE (10-360)   10-14-NLT   10-10-14-NLT   10-14-NLT   10-					CALL CBMP2 (NPLY)TN+CP+AA+BB}	
00 00 1-1-1-1C 00 WRITE (0-330) LPRMJ_1 -1-1-13  00 WRITE (0-330) LPRMJ_1 -1-1-13  01 WRITE (1-330) LPRMJ_1 -1-1-13  01 WRITE (1-330) LPRMJ_1 -1-1-13  02 WRITE (1-330) LPRMJ_1 -1-1-1-13  03 WRITE (1-330) LPRMJ_1 -1-1-1-13  04 WRITE (1-330) LPRMJ_1 -1-1-1-1-13  05 WRITE (1-330) LPRMJ_1 -1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-				C	PLY SIRAINS AND COMPOSITE STRESSES FOR ALL LOAD CONDITIONS.	
No.   100					skite (0,350)	
Willialize Commin Pagameters TJ Gefault Valjes.   1000   Williams   1000   William					0D IOC 11=1, NLC	
ITAKE-10					will (366,361 []	
NS   10				C	COPPOSITE STHAINS.	
ICROIS=0   1120					{};{  - - - - - - - - - - - - - - - - - -	
NSCAL-CO				5	EbiSi=P8(5,1)+bu(1,11)+a8i5,2;+bu(2,11;+bh(5,3)+bu(3,11)	
1400   1400				`	[] (3)-8n(3,1)+PN(1,11)+88(3,2)+PN(2,11)+88(3,3)+PN(3,11)	1630
## ## ## ## ## ## ## ## ## ## ## ## ##				C		
FOLDING   1.00				_		1650
FURNACE   1150						1660
CITCA   1100   AR-SINITHERA    1000   CITCA   1000   ALZ-REAL						1670
CITINGS						1680
Cledit   C						1690
THE ACC.						1700
THE   A-C.				÷		1710
PATE				•		1720
Del Univers   120						1730
1400   11900   1200						1740
IRNO					SET STRAIRS TO HEALMON ARSOLUTE VALUE OF 1.36-20 IN PREVENT	1750
TRANCO		[140B3=]		7		
C				•		
1280   1290	C					
THMIII-INC.   1300						
C UPPER BUDNES ON JOSIGN VARIABLES ARBITRARILY SET = 100.  URBITINGG.  C PLY STIFFFESS CONFICIENTS.  CALL CEMP) (NPLY, THN, Ft, FT, GT, PNLT, PRTL, CP)  NN1=2C  NN1=2C  NN3=2C  NN3=2		THN(11=Tnh(1)/>7.29>776				
70 VUB([1=10G.  C + Y STIFPLESS CULFICIENTS.  CALL C(HP) (NPLY,THN,Ff.rET,GLT,PNLT,PRTL,CP)  AN1=2C  AN2=5CC  AN3=20  AN3=20  AN3=20  AN3=2C	C	UPPER BOUNTS ON JESIGN VARIABLES ARBITRARILY JET = 100.		•		
C	70					
CALL CCMP1 (NPLY,THN,FfcET,GLT,PNLT,PRTL,CP)  NN1=2C  NN2=5CC  NN3=2D  NN3=2C  NN4=2C  NNA=2C	C	PLY STIFFRESS Cucficients.				
NN1=2C   1360   1360   15 (25 (27 (10.1) \$7 (25 (27 (10.1) \$7 (25 (27 (10.1) \$7 (25 (27 (27 (27 (27 (27 (27 (27 (27 (27 (27		CALL CCMP1 (NPLY, THN, flift, GLT, PHLT, PRTL, CP)				
NN2=5CC		6N1=2C				
NAT		hNZ=5GC				
NRIA=2C		N2:3=20				
180		644×2C	1370			
15   (ACALC-LE-0-1) CALL CUMMIN (CUMP3-083-x, 0F-,6):15C-,1C-A,5):16:05C,1C-A,5,5,5,5,5,5,5,5,5,5,5,5,5,5,5,5,5,5,5		hH5=4C				
*\$1,d_v\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\		IF (NCALC.EG.O) CALL CUNMIN (CUMP3. Od x, DF. G, ISC, IC. A, S, GI, G2.C	∍H 1390			
C PRINT ANALYSIS RESULTS. 1416 70 CNITACT 16 16 17 17 18 18 18 18 18 18 18 18 18 18 18 18 18		•\$1,d,VLB,VUB,SCAL,NN1,NN2,NN3,NN4,NN5)	1400			
1420   1420	c					
#RITE (6) \$50   TITLE   1440   LDU CONTINUE   1940	_			·		
#RITE to 333)  PP=1CC./UDJ  C PLY THICKNESS: AND PERCENT OF TOTAL THICKNESS: 1460 #RITE to 250 1900  C PLY THICKNESS: AND PERCENT OF TOTAL THICKNESS: 1460 #RITE to 250 1900  D3 80 1=1,NPLY 1470 #RITE to 250 1900  J=1,NPLY UJ 16		∍R1TE (6,)15G) TITLÉ			PATES (DISC) SERINISH 1931	
PP=1CC./UBJ  C PLY THICKNESS: AND PERCENT OF TOTAL THICKNESS. 1460 WHITE top=361  DB ac 1=1;NPLY 1470 BB 12C 1=1;NL 1980  J=thK 1] 1480 UI 10 =1:3 1980  TH([]=xtJ) 1990 110 G13=NLJ;11/CBJ 1990						
C PLY THICKNESS: AND PERCENT OF TOTAL THICKNESS: 1460 WHITE TO SAND 1970 1970 1970 1970 1970 1970 1970 1970		PP+1CC.fupj		Ç		
00 to 1=1=NPLY 1470 Ed te ===================================	ε	PLY THICKKLSSES AND PERCENT OF TOTAL THICKNESS.				
J=[hk(1) 1480 110 G(1)=k(3,1)/C93 1990 Tk(1)=k(3) 1990 110 Jan	-		1470			
TM(1)=X(1) 100 110 (1)=X(1)=X(1) 110 (1) (1) 110 (1) 110 (1) 110 (1) 110 (1) 110 (1) 110 (1) (			1400			
			1470	110		
			1500		MAIL (0)4001 1+(G(J])J*1+31	2000

	COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND	JULY, 1974
120	CONTINUE	2010
C	COMPOSITE STIFFMESSES.	2020
	WRITE (6,160)	2030
	Sf-100.	2040
	IF (AllL.GT.1.)t-10) SF=AA(1,13/AL12	2650
	1f (Sf.Gf.1co,) Sf=1at.	2060
	WRITE (0,17C) AA(1,1),AIIL,SF	2070
	SF=100.	2080
	15 (822L.i.Tachtel) 5F=AA(2,2)AA2L	2090
	if (\$f.di.100.) \$f-100.	2100
	WRITE (6,10G) AA(2,21,A22L,SF	2110
	SF = iGC.	2120
	1f (Attl.GT-1.GE-10) SF=AA(3,3)/A66L	2130
	IF (SF-G1-1CG-) SF+100.	2140
	WRITE (6,190) 44(3,31,4061,8f	2150
	mRITE (6,410)	2160
	DJ 130 I=1,5	2170
	DO 13C J=1,3	2180
	84(1,1)=091+80(1,1)	2190
136	Lante to the terminal of the t	5500
C	COMPOSITE STRESS-STRAIN PELATIONSHIPS.	5510
	hRIIE (6,420) ((AA(i,J),J=[,3],[=1,3)	5550
_	WRITE (6,436)	2230
¢	COMPUSITE STRAIN-STRESS RELATIONSHIPS.	2240
	WRITE (6,44C) ((BB([,4],4=[,3),1=1,3)	2250
Ċ	COMPOSITE ELASTIC CONSTANTS.	22£0
	[X=1./b0(1.1)	2270
	EY*1./88(3,2)	2280
	GXY=1./8B(3,3)	2290
	byx.=-pq(1*5)\78(1*1)	2300
	PRYX=-86(1,2)/u8(2,2)	5310
	HRITE LOINDU) EXIEYIGXYIPRXYIPRYX	5350
	63 76 10	2330
C		2340
140	FORMAT (1544)	2350
150	FURNAT (/14%, 5mf11cE/14%, 15a4)	2360
166	FURRAT (//25x, 30mCOMFO) ITE MEMBRANE STIFFNESSES/27x, ontactual, 7x,	
	TRECUIPEU/27x, SHVALUE, 9X, SHVALUE, dx, GHS. F. 1	5390
176	FORMAT (19x,3H411,E13.5,1x,E13.5,3x,F7.2)	2390
100	PORMAT (14x,3m422,213.0,1x,213.5,3x,F7.2)	2400
196	FURFAT (14x,3HAb5,613,5,1x,613,5,3x,F7,2)	2410
500	FORMAT (1615)	2420
210	FORMAT (5F1C-2)	2430
25C	FORMAT(//41x+2HGF//30x+2pHSYMMETRIC COMPOSITE PANEL)	2440
230	FORMAT (//27x,254ND. OF PLYS *. IS,/,27x,25HND. OF LO	
36.5	1 COMBITIONS *, [5]	2460
240	FORFAT (//25x,35HPLY PROPERTIES - ALL PLYS IDENTICAL/26x,22HLDNG	IT 2470
	1001MAL MULULUS =, L12.5/26x, 22HTRANSVERSE MUDULUS =, £12.5/26x, 2	
	25HtAx +000LUS =,c12.5/26x,22HPOISSUNSS HATID, L=T =,E12.5 3cx,22HPOISSUNSS RATIL, T-L =,E12.51	
	acasecurussames selibs int estitis	2500

	COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMMO JULY,	1974
250		2510
	1ABLE NUMBERS/2G2,47HPLY NO. THICKNESS THETA DES. VAR. NO	2520 2530
Zóù	(S.D13,c.613,XE,9;1,XE,9) 1AMRLA	2540
270	FORMAT (15%,19,3%,113,5,3%,47,2,5%,15)	2550
260	FORMAT 1//352,17HPLY STRAIN LIMITS/14x,23HLONGITUDINAL STRAIN.GE.,	2560
	1:13.5.54 .ANC.LE., E13.5/19x, 23H TRANSVERSE STRAIN.GE., E13.5,9H .A	2570
	2ND-LE-FE13-5/14X,23H SHEAR STRAIN-GE-FE13-5,9H .ANC.LE-FE13-	2580
	35)	2590
5.10	FURMAT 1//35%, LOMSTIFFMESS LIMITS/33%, 7HA11.GE., E12.5/33%, 7HA22.GE	2600
	i.,f12.5/33x,7n465.66.,e12.5)	2610
300	FORMAT [//4GX:50:LOADS/15x;10HLDAD COND.;6cx;2HNx;12x;2MMY;12x;3HNXY	2620
	11	2630
310	Fultal (15x,16,0x,612,5,2x,612,5,2x,612,5)	2640
326	FORMAT (1H1, Zok, 10H) ESION AND/OK ANALYSIS RESULTS!	2650
330	FORKAT L///35K,15HPLY INFORMATION/25K,32HPLY NO. THICKNESS	2660
	1 PERCENT)	2670
340	FUPRAT (35%,104,3%,104/234,11HFHICKNESS =,E12.	2680
	15e4kech1CC.CE1	2690
350	FORMAT 1////37x, 11mmLY STRAINS/33x, 23H5.f SAFETY FACTOR/33x, 26H	2700
	1EPL . LONGITUDINAL STRAIN/33X, 24-1EPT . TRANSVERSE STRAIN/33X, 19H	2710
	ZEPLI . SHEAR STRAIN)	2720
36C	FURRAT (//3cx,10HLJAD CUND.,15/54.7NPLY NO.,0x,3HEPL,0x,4HS.F.,8X,	2730
	L3HEFT, DX, 4HS.f., 3x, 4HEPLT, 7x, 4HS.F.)	2740
37L	FORMAT (54,15,1x,12.5,2x,F7.3,2x,E12.5,2x,F7.3,2x,E12.5,2x,F7.3)	2750
36C	FORMAT CIEX, 47HCOMPUSITE STRAIMS REFERENCED TO STRUCTURAL AXIS/5X,	2760
396	16HLFx = +612.5,3x,6HEFY = +612.5,3x,7HEFXY = +612.51	2770
370	FURMAT 1//25x, 30HMEABRANE STRESSES IN CUMPOSITE/LDX, LUHLDAD COND.,	2780
400	15%,7H51GMA-3,0%,7M51GMA-7,7%,omTAU-XY) FOPPA1 (15%,15,7%,1513,5)	2790
31÷		2800
410	FURTAT 1//2CA,42MCDEFICIENTS OF STRESS-STRAIN RELATIONSHEPS/28X,26 INPLIATED TO STRUCTURAL AXES)	2810
420		\$950
720	FORMAL (10%) CHC11 = \$112.504 K DOHC12 = \$122.504 K, 6HC15 = \$123.504 K,	2630
	1/325.6122 * .:12.5.4%,5HC26 * .:12.5/20%,4HSYHHETRIC.25%,6HC66 * 2.:12.53	2840
430	FORMAT (//ZUA,42HLGEr 1C.ENTS JE STRAIN-STRESS RELATIONSHIPS/284,26	2850
730	THEFTALLY IC ZIENCINSAT WEEK!	2660
440	FORMAT (160,ch011 = ,£12.5,40,ch012 = ,£12.3,40,ch015 = ,£12.5,40,	2670
	1/32x,eh022 = ,£12.5.4x,oh020 = ,£12.5/20x,945YHMETRIC,25x,64066 =	2000
	SPEISTS - VERENANDONGED - PETSTON SOCKANDI LINE EKIT NESS ON NESS	2890
4:6	#JPHAT (//26x, 27HCOMPOSITE ELASTIC CONSTANTS/LIX-SHEXE12.5.5x.	2900
	15HEY * + 12-344 + 6HSAY * + 12-3/94 - 7HNUAY * + 12-3/34, 7HNUAK * +12	2910 2920
	+2.5)	2930
466	FGRMAI(In:,Sdx,bHDESIGN)	2940
470	FORMAT(1H1,37k,3MANALYSIS)	2950
	END	2960
		L 70Q

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	COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND - COMPI JULY:	1974
	SUBPOUTINE LUMPS (MPLY) THN, EL, ET, GLT, PRLT, PRTL, CP)	10
	01#E45[GA CP(3,3,16), THN(18)	20
E	ROUTINE TO CALCOLATE PLY STIFFNESS COEFICIENTS - ALL PLYS THE SAME	30
€	ELASTIC PROPERTIES.	40
¢	BY G. N. VANDERPLAATS SEPT. 1973.	50
ç	MASA-AMES RESEARCH CONTER, MOFFETT FIELD, CALIF.	60
C	MATERIAL ELASTIC PROPERITES.	70
_	PR1=1./(1PRLT+PRTL)	80 90
¢	EQUATION AIO	100
_	C11=E1 *PR1	110
¢	EQUATION All	120
	C12=PklL+EL+PR1	130
С	EQUATION ALZ CZZ=EI+PRI	140
С	EOLATICH AI3	150
·	CQP*CF1	160
С	GO FUR ALL PLYS.	170
·	00 1C 1*1*VELA	180
	THE TA = THA (I)	190
c	FUPATION VO	200
•	AL =COS (THETA)	210
	AM-SIN(INETA)	220
	AL 2 AL +AL	230
	AL 3-AL 4AL 2	240
	AL4=AL2*AL2	250
	AA-1A=SMA	250
	54*44.2	270
	≤14.4°₹ 4.4 = 214.4°€	280
C	EUUATILN AB	29u
	CP(1,1,1)=C11*4L4+2.*C12*4L2*4M2+C22*AM4+4.*C66*AL2*AH2	360
C	EQUATION AS	310
	Cb [1'5'11=C11*VT \$#V45+C15*(VT 4+VH4)+C55*VT5*VH5-4**C00*YT5#VH5	320
Ç	EQUATION AS	330
	C#11,3,11-C11*4L3*4M+C12*(aL*AA3-AL3*44)-C22*AL*AA3+2.*C66*(AL*AA3-AL3-AL3-AL3-AL3-AL3-AL3-AL3-AL3-AL3-	340 350
	1-4M44(3)	360
C	FOURTIEN AC	376
_	CP(2;2;1)*C11*AH4*2.*C12*AL2*AM2+C22*AL4*4.*C66*AL2*AM2 EQLATION A7	380
C	CP(2,3,[)=C11*4L*4H3+C12*[aL3*AH-AL*AH31-C22*AL3*AH+2,*C66*[AL3*AH	390
	1-41*4831	400
¢	FUDATION AD	410
4	CP[3,3,[)=C11+At2*AM2-2.+C12*AL2*AM2+C22*At2*AM2*C66*(At4-2.*At2*A	420
	172+8H41	430
С	IMPOSE SYMPETRY ON CO.	440
-	CP12e1e1}=CP{1>2>{}	450
	CP (3,1,1) = P(1,3,1)	460
	CP(3,2,1).CP(2,3,1)	470
10	CDh) Ince	480
	RETURN	490
	GM3	>00

	COMPOSITE AMALYSTS AND DESIGN PROGRAM - COMAND - COMPS JUL	Υ,	1974
	SUBROUTINE COMP2 (NPLY.TN.C(.A.B)		10
	CIMENSIJN A(3,3), B(3,3), Thile), Cri3,3,14)		20
C	AGUTINE TO CALCULATE MEMBRANE STIFFNESSES AND FLEXIBILITIES OF		30
C	COMPOSITE MADE UP OF RPLY PLYS, EACH WITH THE SAME MATERIAL		40
£	PHOPERTIES.		50
C	BY G. N. VANUERPLAATS SEPT., 1973.		60
c	hasa-ames research center, Hüffelt field, Calif.		70
Ç	STIFFNESS CUEFICIENTS.		BO
C	ZERG A.		90
	00 10 1=1,3		100 110
	Ed IC u=le3		120
10	A(1,2)=0.		130
C C	EUILD A BY SUPERPOSITION.		140
L	LOLATICH AZ CO 30 1-1,4PLY		150
	1• IN(1)		160
	00 20 4*1,3		170
	60 2C N=J+3		180
26	A(J+K)=A(J+R)+T+C+(J+K+I)		190
10	Cublinte		260
Č.	IMPOSI SYRRETRY DY A.		210
	A(2,1)*A(1,2)		220
	A(3,1)*A(1,3)		230
	15,21*15,21		240
Ç	FLEXABILITY COEFICIENTS - INVERSE OF STIFFNESS.		250
c	duito 8-a-inversi.		260
	DE 1-A[1,1]+A(2,2)+A(3,3)+2.+A(1,2)+A(1,3)+A(2,3)+A(1,1)+A(2,3)+A(2		270
	1,31-412,21-411,31-4(1,3)-4(3,31-4(1,2)+4(1,2)		240
	DET-1-/6ET		300
	#(1,1)*0&1*(4(2,2)*4(3,3)*4(2,3)*4(2,3); #(1,2)*GLT*(4(1,3)*4(2,3)*4(1,2)*4(3,3);		310
	111,31=061=(A(1,2)+4(2,3)-A(1,3)+4(2,2;)		320
	B:2,23.0(7.4(1,1).4(3,3)-4(1,3).4(1,3))		330
	S(2,3)*U£T*(A(1,2)*A(1,3)-A(1,1)*A(2,3))		340
	0(3,3)*BeT*(A(1,1)*A(2,2)-A(1,2)*A(1,2))		350
C	IMPOSE SYPHETRY ON 3.		360
-	8(2,1)=8(1,2)		370
	8(3)(1)=6(1)3)		380
	B(3,21=B(2,3)		390
	Ré TURA		400
	EnD		410

COMPOSITE AMALYSIS AND DESIGN PROGREM - LEMAND - COMPS JULY.	197
SUBRESTINE CLMP3 (14FG, DBJ, X, DF, G, IC, A, H1, H2, H3)	10
COPMON /CHMH1/ 1PRINT, NOV, ITHAX, NCON, NS IDE, ICKOIR, NSCAL, NFBG, FOCH,	20
1FBCHH,CT,C1Hlm,CTL,CTLMIN,THETAL,PHI,NAC,DELFUH,DAUFUH,LINO	31
2BJ,1TRM,1TEP,1MFGG	46
01MENSION REAL (**DECNIE) **GCN2**********************************	50
EXTERNAL POUTTHE FOR COMMEN FOR COMPOSITE PANEL DESIGN.	60
by G. N. VANDEPPLAATS SEPT., 1973.	70
NASA-APES RESEARCH TENTER, MCFFETT FIELD, CALIF.	60
THIS 15 A BUFFER BETWEEN COMPIN AND COMPA.	90
CALL CLAPS (INFO, DHJ, HDV, CT, CTL, NAC, K, OF, G, 4, IC, N1, N2, N3)	100
+ETURN	
END	110
thu .	120

and the second s

	COMPANY TO ALLEGATE AND DEPART PROPERTY AND ADDRESS.	
	COPPOS. TE ANALYSIS AND DESIGN PROGRAM - COMAND - COMP4 JULY,	1974
	SUBBLUTIAL COMPS (INFO, OBJ, NUV, CF, CTL, NAC, X, OF, G, A, LC, NN1, N	10
	*I , NN3 }	20
	COMMUN /COMPUS/ MPLY.EL.ET.GLT.PRLT.PRTL.EPLC.EPLT.EPTC.EPTT.GMLT,	30
	INLC.4111.4221.4661.7h(16), THH(16),CP(3,3,18), PN(4,5),AA(3,3),BB(3 2.3),EP(3).5(P(3),LHC(16)	40
	DIMENSION IMP(3), KCMM1), DF(KM1), G(NM2), IC(NM3), ACRM3, MM1)	50
С	ROUTING TO CALCULATE FUNCTION VALUE, CONSTRAINT VALUES AND	60
č	GRABILAT OF FUNCTION AND ACTIVE CONSTRAINTS FOR COMPOSITE	80
č	AMALYSIS AND DESIGN PROGRAM - COMMAND.	90
č	BY G. A. VANUERPLAATS SEPT., 1973.	100
č	NASA-AMIS RESEARCH CENTER, VCHHETT FIELD, CALIF.	110
	1F ([NFU.61.2] 60 TO 20	120
C	CAJECTIVE	130
	un J = G	140
	OU 10 1-1,NFLY	150
	J-thk(I)	160
	THE1)=>(J)	170
10	[3J=[6J+]V(]]	180
	1F (INEU.1G.]) RETURM	190
	IF (INFO-LE-21 GJ TJ 50	200
SC	CONTINUE	210
ε	GRADIENT CF COUFCTIVE	220
JC.	CO 3G I=1, NEV L+(1)=C.	230
34	00 40 E=1, hPLY	240
	J=LAK(1)	250
40	DF(J)*[F(J)*].	260 270
	IF (INFO-EC-31 RETURN	280
50	CUNTINUE	290
Ç	CUNSTRAINTS AND SHADIENT OF ACTIVE CONSTRAINTS.	300
	NC TL 1 = C	310
	ir tinfj.c nac.o	320
Ç	SFIFFNESS AND FLEXIBILITIES.	330
	CALL CCHP2 INPLT. TN. CP. 44.381	340
	D3 176 1=1,NEC	350
C	INVERSE OF EGUATION AL.	360
	EP(1)+65(1,1)+PR(1,1)+ou(1,2)+PR(2,1)+66(1,3)+PR(3,1)	370
	tr(2 =bbic,1100N(1,11+BB(2,21+PN(2,11+BB(2,31+PN(3,11	380
	EP(3)=64(5,1)*PH(1,1)+86(3,2)*P4(2,1)+86(3,3)*PH(3,1)	396
	00 170 J=1:APLT	400
	[HE]A=[Hh(J]	410
	AL=CG17H:161 AH=S1::(TH:1:3)	420
	\$12=\$104L	430
	MK5=Mt+4F	440 450
С	E-UATICN A14	460
-	EP1=ac2+t/1)+am2+cP(2)+aL+ak+6P(3)	470
	LP2-ARZ=1P(1)+AL2-EP(2)-AL+AH+CP(3)	480
	(E) 43-2-3-2 444 (24-21-1911) 1 41-4-4 44-4 44-4 44-4 44-4 44-4 44	490
	hC1G1#AC16141	500

JULY. 1974

	COMPOSITE ANALYSIS AND DESIGN PROJRAM - COMAND - COMP4	JULY, 1974		CUMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND - COMP4
	N1 •NC1CT	. 510		IF (G(N1).LT.CT) GO TC 110
C	LONGITUDINAL STRAIN CONSTRAINT - COMPRESSION.	520	C	GRADIENT CE ACTIVE LUNGITUDINAL TENSILE STRAIN CONSTRAINT.
	GINCTOTI-EP1/EPLC-1.	530		NAC-NAC+1
	NC TOT • NC TOT • 1	540		IF (NAC. C.NN3) RETURN
c	LONGITUDINAL STRAIN CONSTRAINT - TENSION.	550		A(NAC,K)=A(NAC,K)+DEP1/EPLT
	G(NCTGT)=EP1/EPLT-1.	500		1C (NAC)=N1
	MCTGT+ACTL1+1	570	110	
C	TRANSVERSE STRAIN CONSTRAINT - COMPRESSION.	580		IF (GIN1).LT.CT) GG TO 123
	G(NCTCT)=LF2/EPTC-1.	590	C	GRADIENT OF ACTIVE THANSVERSE COMPRESSIVE STRAIN CONSTRAINT.
	NCTGT=NCTGT+1	600		NAC*NAC+1
C	TRANSVENSE STRAIN CONSTRAINT - TENSION.	610		IF (NAC. CC. NN3) RETURN
	GINCTLT) - LP2/EPTT-1.	620		A[hAL,k]=A[hAC,K]+UE; 2/EPTC
	NC TOT+NCTUT+1	630		IC (NAC)=N1
C	SHEAR STRAIN CONSTRAINT.	640	120	N1-N1+1
	GINCTCT) *AbS(EP3)/GMLT-1.	650		IF (G(N1).LT.CT) GD TC 130
	16 (INFO.LT.4) GU TO 160	660	C	GRACIENT OF ACTIVE TRANSVERSE TENSILE STRAIN CONSTRAINT.
	PAC-NAC	670		NAC-NAC+1
	DD 60 F-N1-NCTUT	680		IF (NAC.EQ.NH3) RFIUHN
	IF (G(K).GE.CT) MAC+MAC+1	690		A(NAC,K)=A(NAC,K)+DEF2/EPTT
60	CUNTINLE	700		IC(NAC)=N1
ou	IF (MAC.LC.NAC) GO TO 160	710	130	N1-N1+1
	N2-NAC+1	720		IF (6(N1).LT.CT) Su T/. 140
	DU 70 11-N2, MAC	730	C	GRACIENT OF ACTIVE SHEAR STRAIN CONSTRAINT.
	CO 70 JJ*i,NGV	740		NAC-NAL+1
70	A(II,JJ)-C.	750		IF (NAC.LO.NN3) REIURN
70	MAC+NAC	760		SIGN=1.
		776		IF (LP3.LT.U.) SIGN=-1.
	N2 • N1	780		A(NAC, N) = A(NAC, N)+SIGN DEP3/GMLT
	DO 15C KK-1-NPLY	790		IC (NAC) = n2
	K-LNK(AK) GRADIENT OF STRAINS - EQUATION 37.	800	140	CONTINUE
C		610	150	
	DO 60 +1=1,3	820	100	
	TMP(K1)=C.	830	170	
	DU 6C K2*1,3	840	c	CUNSTRAINTS ON STIFFNESS.
80	IMP(K1)=1MP(K1)+C+(K1+K2+KK)+E+(K2)	850		NI=NCILT
	CO 9C K1*1,3	860		IF (A11L.11.1.36-10) 60 10 100
	DEP(K1)=C.	870	c	CONSTRAINT ON ALL.
	00 90 K2*1,3	880		NCTGT+NCTGT+1
30	DEP(K11=DEP(K11-93(K1,K21+TMP(K2)	890		G(ACTOT)=1AA(1.1)/A11L
	CEP1*AL2*DEF(11+AA2*DEP(2)+AL*AM*DEP(3)	900	1.6	16 (AZZL.LT.1.0E-10) GG TO 190
	LEPZ=AMZ+LEP(1)+ALZ+UEP(2)-AL+AM+DEP(3)		c	CUNSTRAINT ON AZZ.
	DEP3-2.+1: +AH+(DEP(2)-DEP(1))+(AL2-AM2)+DEP(3)	910		NCTLT=NCTCT+1
	NAC-MAC	920		
	N1 = N2	930	100	1F (Acct.cl.110) Gu 1) 200
	IF (G(N1).L1.C1) 60 TO 100	940	190	
C	GRADIENT OF ACTIVE LUNGITUDINAL COMPRESSIVE STRAIN CONSTRAIN	NT. 950		CONSTRAINT ON A66.
	MAC+MAC+1	960		NCTLT+NCTLT+1
	IF (NAC.EC.KN3) WETURN	970		G(NCTOT)=1AA(3,3)/AC6L
	A(NAC,+)=A(NAC,K)+DEP]/EPLC	980	200	IF (INFO.LT.4.DR.N1.EC.NCTJT) RETURN
	1C (NAC)=N1	990		16 (A11L.LT.1.0E-10) GO TO 230
106	M1+N1+1	1000		K1=N1+1

100	e di	그 생생 아내를 하는 것은 것 같습니다면 하는 사람들이 가장 아내면 이 살림이다고 했다.			1.	1.1		大,一点就是一个一个,是有人的,所以的是否是人的。所以"大"的"大"的"大"的"大"的"大"的"大"的"大"的"大"的"大"的"大"的
							14.3	
San San	1.0	COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND - COMP4	QULT,	1974:			100	COMPOSITE ANALYSIS AND GESIGN PROGRAM - COMANO - COMP4
	-: '	<u> </u>				1.		
		RL-NCIGT		510		1.7	_	IF (GIALIALTACTI GO TO 119
		LUNGITUDINAL STRAIN CONSTRAINT - COMPRESSION.		520		3.5	C	GRADIENT OF ACTIVE LUNGITUDINAL TENSILE STRAIN CONSTRAINT.
49a - 1	100	GINCTOT) = EP1/EP1C-1.		530				NAC*NAC+1
	197	MCTOT=NCTOT+1		540		111	100	IF thac. eo. nk3) return
C		LONGITUDINAL STRAIN CONSTRAINT - TENSION.		550	200	4.00	100	A[BAC.K]#A[NAC.K]+DEPI/EPLT
4.0		GINCTOTI=EP1/EPLI-1.		560		4.00	200	IC (hac) eni
), " _ 1.		RCTGT=RCTGT+1		570	1.50	100	110	M1=N1+1
C		TRANSVERSE STRAIN CONSTRAINT - COMPRESSION.		5B0		٠,	- 1	IF (G(N1)+LT+CT) GG TO 120
A.		GEHCIOT:=LHS/EPTC-1.		590			C	GRADIENT OF ACTIVE THANSVERSE COMPRESSIVE STRAIN CONSTRAINT.
- L		ACTG[=ACTG]+1		600				NAC=NAC+1
		TRANSVERSE STRAIN CONSTRAINT - TENSION.		610				IF (NAC.EC.HN3) RETURN
100		GENCTET1=E82/EPTT=1.	1.00	620				ACDAG, KI = ACHAC, KI +UET 2/EPTC
		NC TOT+NCTOT+1		630				IC (NAC) = N1 (1) (1) (1) (1) (1) (1) (1) (1) (1) (1
C		SHEAR STRAIN CONSTHAIRT.		640			126	
	1.5	GCNCTCTY+A65(EP3)/GMLT-1.		650		1.		IF (G(NI).LT.CT) GO TO 139
		IS (TRED. T. 6) GO TO 160	• •	860			C .	ORACILAT OF ACTIVE TRANSVERSE TENSILE STRAIN CONSTRAINT.
	ani.	MACHNAC	3.5	670	4.0			NAC=NAC+1
San F	28/3	CO 6C K=h1,hCTOT		6BD.				IF (NAC. ED. NH3) RETURN
		IF (G(K).Ut.CT) MAC=MAC+1		690				ACNAC+N1=ACNAC+K1+DEF2/EPTT
60		CUNTIBLE	- 1	700		1 '	- 1	IC (NAC) = N1
* 1.5 F T	10	IF [HAC. EO. NAC] GO TO 160		710			130	M1=N1+1
etil,		NZ=NAC+1	1.1	720		- 1		16 (6(N1)+67-CT) Gu TV 140
		00 70 11=h2;H4C		730		100	C	GRAGIENT OF ACTIVE SHEAR STRAIN CONSTRAINT,
2.1		CO 70 JJ*1,NGV		740			- 7	NAC=NAC+1
70		ATTI-JUI-C.		750			1.5	IF (NAC.LO.KN3) RETURN
		MAC*NAC		760			1.0	SIGN#1.
		N2*N1		770	100	100		IF (EP3.LT.U.) \$1GN=-2.
· H		DD 15C KK#1+hPLY		780				A(NACAH)=A(NACAH)+SIGN+NGEPB/GMLT
199		K-LHK(AK)		770				1C(hAC)=n2
c		GRADIENT OF STRAINS - EQUATION 37.		800			146	
		00 60 11=14 06 00	25.0	810		1.4	150	CONTINUE
· 100		TMP(k1)=0.		820		100	160	
: ' ' .		DU 80 K2*1,3		830	A *		170	CONTINUE
		THP(K1)=TMP(K1)+CP(K1)+K2+KK)+EP(K2)	4.			1.0	Ĉ.	CONSTRAINTS ON STIFFHESS.
BQ				840				NI*NCTLT
		CO 9C KI=1,3		450				
6 G		DEPTK11=L.		860		1.00	-	IF [AllL.Li.1.Je-10] GO TO Tav
		DO 90 k2=1,3		870			С	CONSTRAINT ON ALL.
90		Dep(K1)*DEP(K1)-B8(K1,K2)*THP(K2)		880	100			ACTOT=ACTOT+1
1.		DEP1=AL2+DEF(1)+AA2+DEP(2)+AL+AH+DEP(3)		890				GINCINII=1,-AA(1+1)/A11L
		GEPZ#AHZ4CEP(11+ACZ4UEP(21-AC#AH+DEP(3)		900		24.0		1f [A72C.LT.1.0E-10] GG TO 193
1.4.7		DEP3=2.+#: +AH+(DEP(21-DEP(11)+(AL2-AH2)+DEP(3)		910		100	C	CONSTRAINT ON AZZ.
4.		MACRHAC		920		·	- 17	NCTCT=ACTCT+1
		MI = N2		930			100	GCACTUT)=1AA(2,2)/AZZL
- 12		if (G(N1).LT.CT) GO TO 100		940		1.0		IF (Actt.11.1.01-10) GU 10 200
C	100	GRADIENT OF ACTIVE LUNGITUDINAL COMPRESSIVE STRAIN CONSTRAINT.		950			C	CONSTRAINT ON AGG.
		NAC = NAC + I		960	· // // //	· ' .	1	NCTLI*ACTLI*A
17.	10	IF (NAC.EC.KN3) RETURN	- 11	970	**	100		G(RCTOT)=1AA(3.3)/A66L
14.00		ACHAC + 1 = A (IIAC + K) + DEP1/EPLC		980		100	205	IF (INFO-LT-4-DR-N1-LG-NCTDT) RETURN
		IC(NAC)=H1		990				1 (A11L.LT.1.9E-10) Gu TO 230
100		MI*NI+1		TUOD				* NI = NI + 1
		TT TTT 기계에 가꾸고 있는 기계에 가는 사이를 가고 있습니다.	14		3746.0	2.	4000	요즘 마음 아래도 하다는 것은 사람들이 방법이 많아 이렇다면 살다.
								医电子性切迹 医电子性切迹 化二甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基

### References

- Schmit, L.A., Jr., and Farshi, B.: Optimum Laminate Design for Strength and stiffness. Int. J. For Numerical Methods in Engineering, Vol. 7, No. 4, pp. 519-536, 1973.
- Vanderplaats, Garret, N.: CONMIN A FORTRAN Program for Constrained Function Minimization - User's Manual, NASA TM X-62,282, Aug. 1973.
- 3. Advanced Composites Design Guide, Volume I Design, Wright-Patterson Air Force Base, Ohio, January 1973.

# COMAND DATA ORGANIZATION:

Block	Number of Cards	INFORMATION	FORMAT
A	1	Title - Anything may be given here	15A4
В	1	NCALC, NPLY, NDV, NLC, IPRINT	515
С	1	LNK(I),I=1,NPLY	1215
D	1-3	X(I),I=1,NDV	8F10.2
Е	1-3	VLB(I), I=1, NDV (Blank card(s) if NCALC.NE.0)	8F10.2
F	1-3	THN(I),I=1,NPLY	8F10.2
G	1	EL, ET, GLT, PRLT	4F10.2
н	1	EPLC, EPLT, EPTC, EPTT, GMLT, A11L, A22L, A66L	8F10.2
1	NLC	PN(J,I),J=1,3 (One card per loading condition)	3F10.2
		Begin with next set of data - Program terminates  if 2 blank cards are read here.	

TABLE 1 - DATA ORGANIZATION

DATA SHEET

# COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col Block	1_	5	11		21		31		41		51		61		71	
A							-									
В																
C				-												
D						··· , <u></u> -	<u> </u>	<del></del>								<u>.</u>
	<del>,</del>															
	-															
E		<u> </u>						<u> </u>	<u> </u>	<del></del>	<u></u>	<u> </u>	<u> </u>	<u>.</u>		
F		<del>,</del>	· · · · · ·						<u> </u>	i		····	<u> </u>			····
	<del></del>				<u> </u>	<del></del>		<u> </u>			<u> </u>	<u></u>	-			<u> </u>
G						· · · · · · · · · · · · · · · · · · ·										
H		<u></u>													<u></u>	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
I	·	<del> </del>		<u> </u>		<u> </u>	<u> </u>			· · · · · ·		-			-	:
	<del></del>					<del></del>							<del> </del>	<u></u>		
	·								-							
											].					

TABLE 1 - DATA ORGANIZATION - CONCLUDED

TABLE 1, 2, 1-III. KEY UNIDIRECTIONAL PROPERTIES

## HIGH-STRENGTH GRAPHITE/EPOXY -[0]

 $V_{f} = 0.60$ 

				RT	350°F
Design strengths*	Longitudinal tensile ultimate	Ksi	F <sub>L</sub> tu	180.0	180, 0
	Transverse tensile ultimate	Ksi	F <sup>tu</sup> T	8.0	4. 0
	Longitudinal compression ultimate	Ksi	F <sub>L</sub> cu	180.0	70. 0
	Transverse compression ultimate	Ksi	F <sup>cu</sup> T	30.0	12.0
	In-plane shear ultimate	Ksi	F <sub>LT</sub>	12.0	6.8
	Interlaminar shear ultimate	Ksi	r <sup>isu</sup>	13.0	8. 0
	Ultimate longitudinal strain	μin, /in.	$\epsilon_{\mathrm{L}}^{\mathrm{tu}}$	8,700.0	9,650.0
	Ultimate transverse strain	μin./in.	€ tu	4,750.0	4,100.0
Elastic properties	Longitudinal tension modulus	Msi	$\mathbf{E}_{\mathbf{L}}^{t}$	21.0	18.7
[typical]	Transverse tension modulus	Msi	$\mathtt{E}_{T}^{t}$	1.7	0.87
	Longitudinal compression modulus	Msi	Ec L	21.0	18.7
	Transverse compression modulus	Msi	E <sup>c</sup> T	1.7	0.87
	In-plane shear modulus	Msi	GLT	0, 65	0,32
	Longitudinal Poisson's ratio		ν <sub>LT</sub>	0, 21	0, 21
e maka ji kas	Transverse Poisson's ratio		$\nu_{\mathrm{TL}}$	0.017	0. 01 0
Physical	Density	lb/in. <sup>3</sup>	ρ	0.056	0.056
constants [typical]	Longitudinal coefficient of thermal expansion	μin. /in. /°F	$\alpha_{\mathrm{L}}$	-0. 21	-0, 005
	Transverse coefficient of thermal expansion	μin. /in. /°F	$\alpha_{T}$	16.0	21.8

1.2.1 14

Table 2. - Material properties.

References: 1.2-15, -19, -21
\*Typical Design Allowable, reference section 1.2.0

DATA SHEET

# COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col	1	5	11	21	31	41	51	61	71
A	DETER	MINA	TION OF LI	MIT STRAI	NS - G/E C	OMPOSITE			
В	1	1	1 4	0					
С	1								
D	1.0					31,533			
				1					
Е	0.								
	<del> </del>								
F	0.								
	1								
G	210000	00.	17000000.		.21				
Н -	0.		0.	0.	0.	0.	0.	0.	0.
I	180000	٠.	0.	0.					
	0.		-30000.	0.					
	0.		8000.	0.					
	0.		0.	12000.					

TABLE 3 - DETERMINATION OF LIMIT STRAINS - G/E COMPOSITE

### DATA SHEET

## COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col Block	1	5	11		21		31		41		51		61		71	
A	QUASI		-	COMP		UNDER	-	XIAL 1								
В	0	12	1	1	2					:						•
С	1	1	1	1	1	1	1	1	1	1	1	1				
D	.05															
Е	.0000	)1														
F	0.		15.		-15.		30.		-30.		45.		-45.		60.	
	-60.		75.		-75.		90.				-					
G	21000	000.	17000	0000.	65000	00.	.21									
Н	008	57	.008	57	017	6	.0047	1	.0184	4	0.		0.		0.	
I	20000															
										•						

TABLE 4 - QUASI-ISOTROPIC COMPOSITE UNDER UNIAXIAL LOAD - EXAMPLE 1

DATA SHEET

## COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col lock			11		21		31	41	51	61	71
A	(0, 45, -45, 90) GRAD				HITE	ITE EPOXY COMPOSITE - EXAMPLE 2					
В	0	4	3	4	0						
С	1	2	2	3						11	
D	.1 .1			.1							
Е	.00001		.00001		.00001						
F	0.		45.		-45.		90.				
G	21000000.		17000000.		650000.		.21				
н	00857		.00857		0176		.00471	.0184	500000.	0.	0.
I	20000.		0.		0.						
	15000.		-15000.		5000.						
	-15000.		10000.		10000						
	0.		0.		20000						

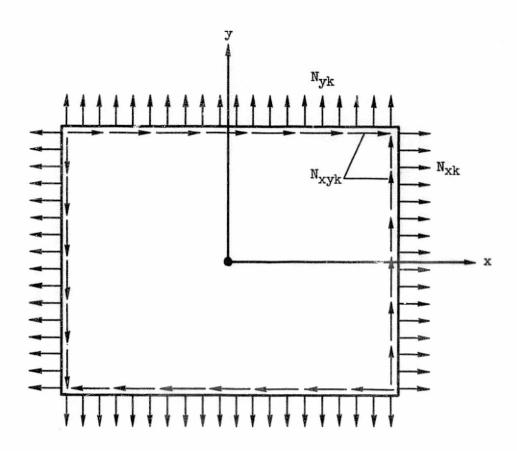
TABLE 5 - (0, ±45, 90) GRAPHITE EPOXY COMPOSITE - EXAMPLE 2

DATA SHEET

# COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

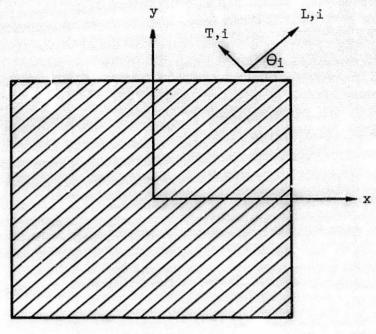
Col	1 5	1 5 11		31	41	51	61	71	
A	(0, 30, -3	0, 60, -60	. 90) GRAPH	ITE EPOXY	COMPOSITE	- EXAMPLE	3 .		
В	0 6								
С	1 2	2 3	3 4					$+$ $\perp$	
D	1.1	.1	.1	.1					
Е	.00001	.00001	.00001	.00001					
F	0.	30.	-30.	60.	-60.	90.			
G	21000000.	17000000.	650000.	. 21					
Н	00857	.00857	0176	.00471	.0184	500000.	0.	0.	
I	20000.	0.	0.						
	15000.	-15000.	5000.						
	-15000.	10000.	10000.						
	0.	0.	20000.						

TABLE 6 - (6, ±30, ±60, 90) GRAPHITE EPOXY COMPOSITE - EXAMPLE 3

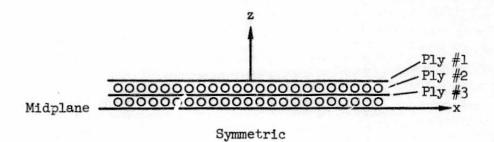


Inplane loads  $N_x$ ,  $N_y$ ,  $N_{xy}$  Load condition k.

Figure 1.- Typical composite loading.



Ply orientation,  $\theta_i$ 



Symmetric composite layup

Figure 2.- Typical ply orientation.

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REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
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ANALYSIS SYMMETRIC COMPOSITE PANEL DETERMINATION OF LIMIT STRAINS . GIE COMPOSITE NO. OF PLYS PLY PROPERTIES = ALL PLYS IDENTICAL LONGITHIDING MODIFIES = .210001+08 TRANSVERSE JODILUS = .170002+07 SFEAR MODIFIES = .210002+00 POISSON'S PATIO, L=T = .210002+00 POISSON'S PATIO, T=L = .170002-01 PLY THICKNESSES, OPICNTATIONS, AND DESIGN VAHIABLE NUMBERS
PLY NO. THICKNESS THETA DES, VAR. NO.
1 .100n0F.01 0.00 1 .AND.LE. -0. STIFFHESS LIMITS 411, CE .. 0. 422.cE.-0. 466.EE .. 0. 10405 LOAD CO.P. .. HXY :1800at-n5 0, - 30000E+05 .12000E+05

DESIGN AND/OR ANALYSIS RESULTS TITLE DETERMINATION OF LIGHT STRAINS . G/E COMPOSITE PLY INFORMATION THICKNESS PERCENT .10000E+01 100.00 THICKNESS . . 10000E+01 100.00 PLY STRAINS
S'F' = SAFETY FACTOR
CPL = LONGITUDINAL STRAIN
EPT = TRANSVERSE STRAIN EPLT . SHEAR STRAIN LOAD CUND. 1 S.F. FPT S.F. 0,000 1,18000F=03 0,000 .85714F-03 .10000E-19 COMPUSITE STRAINS REFERENCED TO STRUCTURAL AXIS EPX = .85714F-83 EPY = -18800E-03 FPXY = 0.

3.F. FPT 8.F. 0.000 1.17647E.U; 0.000 .10000E-19 .30000F=03 COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS
EPY = .30000F=05 EPY = -.17447E=01 FPXY = 0. LAAD COND. 3 PLY NO. EPL .. 80000F=04 5.F. 0.000 EPT 5.F. .10000E-19 LASD COND. 4 PLY NO. 0.000 .10000F-19 0.000 .10000E-19 .18462E-01 COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS EPX = 0: FPY = 0' EPXY = .18462E-01 MEMBRANE STRESSES IN COMPOSITE LOAD COND. \$16Har \$16Har TAU-XY .18000F:05 0. 0. 0. 0. -30000F+05 0. 0. 80000E+04 0. 0. 0. .12000E+05

Figure 3.- Determination of limit strains - G/E composite.

```
| COMPORTE ELASTIC COMPONENT STEPS SEX | STOODE-00 | COMPORTE ELASTIC COMPONENT SEX | STOODE-07 | GXY = .51000E-00 | COMPORTE ELASTIC COMPONENT SEX | STOODE-07 | CAY = .21000E-00 | COMPONER | CAY = .21000E-07 | CAY = .21000E-00 | CAY = .21000E-00 | CAY = .21000E-00 | CAY = .21000E-07 | CAY = .21000E-00 | CAY = .21000E-07 | CAY = .21000E-00 | CAY = .21000E-07 | CAY = .21000E-00 | CAY = .2100
```

Figure 3.- Concluded.

```
OF SIGN
         SYMMETRIC COMPUSITE PANEL
 QUAST-ISOTROPIC COMPOSITE UNDER UNIAKIAL LOAD . EXAMPLE 1
        NO. OF PLYS # 12
       PLY PROPERTIES . ALL PLYS IDENTICAL
       STIFFNESS LIMITS
           411, nt. 0.
422, nE. 0.
466, nt. 0.
               LPARS
 1040 CHND.
         .20000e ins 0.
```

Figure 4.- Quasi-isotropic G/E composite under uniaxial load — Example 1.

```
BEPRODUCIBILITY OF THE
```

```
FURTRAN PROGRAM FUR
                   CONSTRAINED FUNCTION MINIMIZATION
           NASA/ANES RESEARCH PENTER, MOFFETT FIELD, CALIF.
                        VERSION 11
CONSTRAINED FUNCTION MINIMIZATION
CONTROL PARAMETERS
IPPINT NOV
                  PTMAX
                          NOON
                                    USIDE
                                            ICHDIR NSCAL
                                                              NEDG
 5
                   30
                           60
LINORJ ITRY
                      PTHIN
                                                          FILKIN
-. 10000F+00
                    .40000F-02
                                     -. 10000E-01
                                                        -1000UE-02
    THETA
                                                          DABFUN
  .10000F+01
                    .50000E+01
                                      .10000F-03
                                                        .60000E=03
    FORM
                      FUCHU
  .10000F -01
                  .10000E-01
LOWER ROUNDS ON DECISION VARIABLES (VLR)
         .10000F-04
 11
UPPER ROUNDS ON DECISION VARIARIES (VUR)
 13
         .10000F+05
ALL CONSTRAINTS ARE NOVALINEAD
INITIAL FUNCTION INFORMATION
OBJ =
          .60000F+00
DECISION VARIABLES (X-VECTOR)
          .50000E-01
CONSTRAINT VALUES (G-VECTOR)
                                     -,92703E.00 -,12727E+01 -,10000E+01 -,14587F+01
-,1958E.01 -,85510E+00 -,14387E+01 -,56134E+00
        -,14809E+01
                      -.51908E:00
  11
         ., Sel 346 +00
                       -. 94760F .00
                                                                                 -,56134E+00
  71
                                     - 85310E.00
- 13232E.01
- 83447E.00
- 10806E.01
         -. 94760F.00
                       -, 11958E .01
                                                    *,13232E+01
                                                                  -,67678E+00
 131
                                                    -,67678E+00
         -. 985758 +00
                                                                  -. 10058E+01
                       -. 74557E .00
                                                                                 -,98575E+00
                                                    -.10806E+01
                                                                  -. 69882E+00
-. 70621E+00
 251
         -. 74557E+00
                      -.11055E,01
                                                                                 -.70621E+00
-.10078E+01
         .. 11655F+01
                                                    .. 69882E+00
 311
 3/1
         -. 99217++00
                       -. 11574F . 01
                                     -,41188E +00
-,74557E+00
                                                    -. 74557E+00
                                                                  .,10078E+01
                                                                                 -,99217E+00
                       -,41188F,00
                                                    -,89259E+00
                                                                  -,11076£+01
                                                                                 -. 12136E+01
 951
         -. 11574F+01
                       -. 85310F .00
                                     -. 892591.00
                                                    -.11076E+01 -.12136E+01
                                                                                 -,20184E+00
                                                                                  -. 10000E+01
         -. R5510s .00
                       -. 85014F.00
                                     -. 11499t +01
                                                    -. 12342E+01 -. 12495E+00
```

```
ITER #
                                  nBJ :
                                                     .525n4F.00
DECISION VARIABLES (X-VECTOR)
                   .43753E-01
CONSTRAINT VALUES (G-VECTOR)
   1)
                -. 15496F+01 -. 45042E+00
                                                                         -,91661E,00
                                                                                                    -,13110E+01
                                                                                                                                -,10000E+01 -,15013E+01
                 -,49870t+00
                                           -. 94012E .00
                                                                         -,12238t.01
                                                                                                    -,83215E+00
                                                                                                                                 -. 15013E+01
                                                                                                                                                             -,49870E+00
                                                                                                                                                            -,10044E+01
                  -. 94012E+00
                                                                          -. 83213E.00
                                                                                                    -. 13694E+01
                                                                                                                                 -. 63063E+00
                -,401/2E+00 -,12236E+01 -,093/2E+00 -,709/2EE+00 -,1189/2E+01 -,8108/EE+00 -,1179/E+01 -,1179/E+01 -,327/1E+00 -,87875E-01 -,83213E-00 -,87875E-01 -,8
                                                                                                                                                             -. 96372E-00
                                                                          -. 13694E+01
                                                                                                    -, 63063E+00
                                                                                                                                  -. 10044E + 01
                                                                        -.81084E.00
-.10921E.01
-.32791E.00
-.70924E.00
                                                                                                    .,10921E+01
                                                                                                                                  -, 65582E+00
                                                                                                                                                             25)
                                                                                                     -. 65582E+00
                                                                                                                                  -. 66426E+00
                                                                                                    ·,70924E+00
                                                                                                                                                             .,99105E+00
 43)
                                                                                                                                  -. 10089E+01
                                                                                                    -,87703E+00
                                                                                                                                 -,11230E+01
                                                                         -.87703E.00 -.11230E+01
                                                                                                                                  . 12441E+01
                                                                                                                                                             .. 87875E.01
                  -. A3213E+00
                                             -. 82874E.00
                                                                         -. 11713t +01
                                                                                                     -,12676E+01
                                                                                                                                  -,14203t-04
                                                                                                                                                             -,10000E+01
ITER .
                                  nBJ s
                                                       .52504E.00
                                                                                       NO CHANGE IN OBJ
DECISION VARIABLES (X-VECTOR)
                    .45753F-01
CONSTRAINT VALUES (G-VECTOR)
                                                                                                                                -.10000E+01 -.15013E+01
                 -.15496E+01 -.45042E+00 -.91661E+00 -.15116E+01
    13
                                            -.94012E.00
                 -. 49870E+00
                                                                         . 12238E.01
                                                                                                      -,83213E+00
                                                                                                                                  -. 15013E+01 -. 49870E+00
                 -. 94012E+00
                                                                         +,83213E,00
                                                                                                      -,13694L+01
                                                                                                                                 -. 63063E+00 -. 10044E+01
                                                                                                                                                             . 98372E+00
                 -. 98372E+00
                                             -. 70924E.00
                                                                         -. 13694E.01
                                                                                                      -,63065E+00
                                                                                                                                  -,10044E+01
                                                                                                                                                             -, 66426E+00
                  -. 70924F+00
                                             ...11892E.01
                                                                          -.81084E.00 -.10921E+01
                                                                                                                                  ., 65582E+00
                                                                        -.10921E-01 -.65582E-00
-.32791E-00 -.70924E-00
                                                                                                                                                             -. 10089E+01
                  -,11892E+01
                                            -.81084E.00
                                                                                                                                  -, 66426E+00
                                                                                                                                  -,10089E+01
                                                                                                                                                             -. 99105E+00
  371
                  -. 99105E+00
                                                                        -.709246.00 -.87703E+00
-.87703E.00 -.11230E+01
-.11713E.01 -.12676E+01
                                                                                                     .,87703E+00
                                                                                                                                  .,11230E+01
                                                                                                                                                             -,12441E+01
                  -.1179E.01 -.3279E.00
-.87875E.01 -.83213E.00
-.83213E.00 -.82874E.00
  43)
                                                                                                                                  -,12441E+01 -,87675E-01
  491
  551
                                                                                                                                  -.14203E-04
ITFR &
                                                       .525n4E400
                                                                                       NO CHANGE IN UBJ
DECISION VARIABLES (X-VECTOR)
                   .43753E-01
CONSTRAINT VALUES (G-VECTOR)
                                                                        -,91651E.00 -,13116E+01 -,1000E+01 -,15013E+01
-,12238E.01 -,83213E+00 -,15013E+01 -,49870E+00
-,83213E.00 -,13694E+01 -,63083E+00 -,10044E+01
                 -,15496F.01 -,45042F;00
                  -,49870E+00 -,94012E+00
                 -,94012F.00
                                            -.12238E.01
                                                                         -,13694E,01 -,63063E+00
                                                                                                                                  -. 10044E+01 -. 98372E+00
                                            -.11892E.01
-.81084E.00
-.11799E.01
                                                                         -,81084E,00
                                                                                                     -,10921E+01
                  -, 70924E+00
                                                                                                                                  -,65582E+00
                                                                                                                                                             -, 06426E+00
  25)
                  -. 11892F.01
                                                                         -,10921E,01
                                                                                                     .. 65582E+00
                                                                                                                                  -,66426E+00
                                                                                                                                                             -,10089E+01
 31)
                                                                         *,32791E.co
                  -, 99105C+00
                                                                                                                                  -,10089E+01
                                                                                                      -. 70924E+00
                                                                                                                                                             -, 99105E+00
  43)
                 -.11799F.01 -.32791F.00
-.87875E.01 -.83213F.00
-.83213E.00 -.82874F.00
                                                                         -. 70924E.00 -. 87703E+00
                                                                                                                                  -,11230E+01
                                                                                                                                                             .,12441E+01
                                                                                                                                  -,12441E+01 -,87875E-01
                                                                         - 87703E.00 -.11230E+01
                                                                                                                                 -.14203E-04
                                                                                                                                                            -.10000E+01
```

Figure 4.- Continued.

```
FINAL OPTIMIZATION INFORMATION
                                                                                                                                                                                                                                                                                                                                                                                                                        08J .
                                                                                                                                                                                                                                                                                                                                                                                                                                                              .525036F+00
                                                                                                                                                                                                                                                                                                                                                                                                                        OECISION VARIABLES (Y-VECTOR)
                                                                                                                                                                                                                                     -.14000E+01 -.15015E+01
                                                                                                                                                                                                                                                                                                                                                                                                                                1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                               .43753f -01
                                                                                                                                                                                                                                     -.15013E+01 -.49870E+00
                                                                                                                                                                                                                                                                                                                                                                                                                    CONSTRAINT VALUES (G-VECTOR)

1) -15496E4.01 -,45042E4.00 -,49164E4.00 -,13118E4.01 -,15013E4.01

7) -49376E4.00 -,4012E4.00 -,12238E4.01 -,83213E4.00 -,15013E4.01 -,49876E4.01

13) -494012E4.00 -,12238E4.01 -,83213E4.00 -,15043E4.00 -,10044E4.01

19) -803772E4.00 -,1092E4.01 -,83213E4.00 -,10044E4.01 -,83043E4.00 -,10044E4.01

25) -,70924E4.00 -,1092E4.01 -,61084E4.00 -,1092E4.01 -,5552E4.00 -,64226E4.00

31) -,11307E4.01 -,81084E4.00 -,1092E4.01 -,5552E4.00 -,64226E4.00

33) -,1179E4.01 -,32791E4.00 -,70924E4.00 -,1089E4.01 -,99105E4.00

43) -,67375E4.01 -,32313E4.00 -,37703E4.00 -,11230E4.01 -,12441E4.01 -,87875E4.01

55) -,03213F4.00 -,82874F4.00 -,11713E4.01 -,12478E4.01 -,12481E4.01 -,87875E4.01
-40776:00 -,40776:00 -,2238E:01 -,8213E:00 -,1004E:01 -,0503E:01 -,40776:00 -,1004E:01 -,8213E:00 -,1004E:01 -,0503E:00 -,1004E:01 -,6303E:00 -,1004E:01 -,0530E:00 -,1004E:01 -,1004E:00 -,1004E:01 -
                                                                                                                                                                                                                                                                                                                                                                                                                        THERE ARE 1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
                                                                                                                                                                                                                                                                                                                                                                                                                        THERE ARE O VIOLATED CONSTRAINTS
                                                                                                                                                                                                                                                                                                                                                                                                                        THERE ARE O ACTIVE SIDE CONSTRAINTS
                                                                                                                                                                                                                                                                                                                                                                                                                        TERMINATION CRITERION
                                                                                                                                                                                                                                                                                                                                                                                                                                               ABS(1-08J(1-1)/08J(1)) LESS THAN DELFUN FOR 5 ITEMATIONS
                                                                                                                                                                                                                                                                                                                                                                                                                                               ABS(OBJ(I)=OBJ(I=1)) LESS THAN DABFUN FOR S ITLANTIONS
                                                                                                                                                                                                                                                                                                                                                                                                                        NUMBER OF ITERATIONS . 4
                                                                                                                                                                                                                                                                                                                                                                                                                        ORJECTIVE FUNCTION WAS EVALUATED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           5 TIMES
                                                                                                                                                                                                                                                                                                                                                                                                                        CONSTRAINT FUNCTIONS WERE EVALUATED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            S TIMES
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           2 TIMES
                                                                                                                                                                                                                                                                                                                                                                                                                        GRADIENT OF OBJECTIVE HAS CALPULATED
                                                                                                                                                                                                                                                                                                                                                                                                                        GRADIENTS OF CONSTRAINTS WERE CALCULATED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           2 TIMES
```

Figure 4.- Continued.

CHJ . .525n4F100

DECISION VARIABLES (X-VECTOR) .457536 -01

71

131

311 433

1) -. 15496+ 01 -. 45042F-00

-.49870E.00 -.94012E.00

NO CHANGE IN ORJ

-,916612,00 -,131102+01 -,122162,01 -,832132+00 -,832132,00 -,136942+01

```
DESIGN AND/OR ANALYSIS RESULTS
QUAST-TSOTROPIC COMPOSITE UNDER UNIAXIAL LOAD . EXAMPLE 1
                    PLY INFORMATION
                                    PENCEUT
                     THICKNESS
                     . a3753F - 01
                     .43744E-01
                     .43753E-01
                      . 13753E-01
                     .03753F-01
                     . 437536 -01
                     .83753E-01
                     . 43753E-01
                     ,43753E-01
                     . 43753E-01
                     . 95753E-01
                                      6.53
                      .95753E-01
                                      8.55
                                 .........
        THICKNESS # .52504F.+00
                                  100,00
                  S'F' & SAFFTY FACTOR
                  EPL & LONGITUDINAL STRAIN
                  POT & TRANSVERSE STRAIN
                  PPLT . SHEAR STRAIS
                     LOAD COND.
                                    S.F.
11,991
16,700
              1.820
                      -.14677E-02
470995-02
                      -. 10539E-02
429616-02
              1,995
                                              S0-388801,-
42961##02
              1.995
                                     10,700
                                               50=38880£.
. $1655F=02
              2.707
                                     61,412
                                              -,53500F-n2
```

```
-,74776E-10 100.000
                                   .10539E-02
.76694E-04
                                                                              5,957
                                                                              3,459
                                                                              3,439
2,978
2,978
           316555-02
                           2,707
                                                   61,415
                                                              $3500E+02
                                                             -,01777E-02
           .16211F=02
                          5,287
                                     .14211E-07
                                                    2,905
                                                             -,53500E-02
                                                    2,905
1,488
1,488
1,096
                          5,287
           .10211F-02
                                     .16211F-02
                                                                              3,439
           .76694F-04
                        100,000
                                     .31655E-02
                                                             .33500E-02
                                                                              5,439
                                     .31655F-02
            766945-04
                        100,000
          -,10539r-02
                          8,132
8,152
5,839
                                     42961F-02
                                                                              5,957
                                     429611-02
          -,10539F-02
                                                    1.096
                                                              .30888E+02
                                                                              5,957
   11
          -.146775-02
                                     47099E-02
                                                    1.000
                                                               .12648E .08
                                                                           100,000
COMPOSITE STRATUS REFERENCED TO STRUCTURAL AXIS
```

LUAD COND. SIGM.=X SIGMA=Y TAU=XY

EPX # .47099E-02 EPY = -. 14477E-02 FPX1 = -,74776E-10

COMPOSITE MEMBRANE STIFF NESSES

ALTH-AL REGISTED

ALLE VALUE S.F.

A11 .47030E+07 0. 100,00

A22 .47031E+07 0. 100,00

A64 .16187E+07 0. 100,00

COEFICIONES OF STOFSS-STRAIN RELATIONSMIPS

HELATED TO STRUCTURAL AXES

11 \* ,095766.07 C10 = ,38574E.03

C2> = ,095766.07 C20 = ,15584E.00

SYMMETRIC C60 = ,30831E.07

CREFICIENTS OF STRAIN\_STRESS RELATIONSHIPS

RELATED TO STRUCTURAL ARES

U11 # .123046\_00 012 # \_.505305\_07 016 = 0.19630E\_14

27 # .12364E\_00 026 = .62547E\_14

SYMMETHIC

Figure 4.- Concluded.

SYMMETRIC COMPOSITE PANEL TITLE 0. 45, -45, 90 GRAPHITE EPOXY CUMPOSITE . EXAMPLE 2 NO. OF PLYS PLY PHOPEOTIFS = ALL PLYS IDENTICAL LONGITUDINAL MODULUS = ,21000E+08 TRANSVERSE MCDHLUS = ,17000E+07 SHEAR MODILUS = ,5000E+00 POISSON'S PATIO, L=T = ,21000E+00 POISSON'S RATTO, THE . 17000E-01 PI V THICKNESSES, ORIGINATIONS, AND DESIGN VARIABLE NUMBERS
PI V NO. THICKNESS THETA DES. VAR. NO.
1 10000F.00 0,00 1
2 10000F.00 45,00 2
3 10000F.00 45,00 2
4 10000F.00 40,00 5 LONGITHMINAL STRAIN.GE, -.85700E.02 .AND.LE.
TRANSVERSE STRAIN.GE, -.17600E.01 .AND.LE.
SMEAR STRAIN.GE, -.18000E.01 .AND.LE. .85700F-02 .47100E-02 STIFFNESS LIMITS 411.GE. .5000nE+06 466. Et. 0. LOADS LOAD COND. ARY 50000E+04 .2000nf.n5 0. .1500nE+n5 -.150n0F+05 ,10000E+05 .10000E+05 -,1500nF+n5 .20000E+05

Figure 5.- (0, ±45, 90) Graphite epoxy composite — Example 2.

#### DESIGN AND/OR ANALYSIS HESULTS 0. 45, -45, 90 GRAPULTE EPRXY CHAPUSITE . EXAMPLE 2 PLV INFORMATION THICKNESS PEHCENT PLY WD. . 159 SAE +00 27,56 . 18014F.00 \$1.10 .180141+00 31.16 58507F-01 10,12 ........ 100,00 DLY STRAINS S'F. & SAFETY FACTOR PPL = LONGITUDINAL STRAIN FOT & TRANSVERSE STHATH EDLT = SHEAR STRAIN I CAD COND. PI V NO. EPT 8,329 2.062 -. 10912t-09 100,000 .. 21151F -02 415611-02 .102:5E-02 50-359650. .10215F=02 4.611 .102151-02 8,390 1,133 50-354050. 102150-02 4.056 .15167E-08 100,000 -.21131r-02 415011-02 COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS FPX = .41501F-n2 EPY = -.21131F-02 FPXY = -,10912t-09 I MAD COND. FPLT 5.F. 2.802 PI 4 40. 5.F. EPT -.628111-02 7,835 .47019F-02 .25485t=02 -,10983E-01 .. 1963AE-02 5,962 1.075 . 38460F+03 55.540 -,190381-02 . 584645-01 .10983F-01 12.245 4. 564 1.564 -, 23485E-02 1,835 470191-02 1.002 -. 62811r-02 COMPOSITE STRAINS MEFFRENCED TO STRUCTURAL AXIS tor = .47014F-92 FPY = -.62811F-02 FPYY = .23485t-02 LUAD COME. EPLT 5.917 PLY NO. FP1 S.F. 2.053 4 PT -,417366-02 .47157E-02 .46970E-02 -.20770F-32 .20195F-02 8.472 50-356889 2,010 3.272 -.207745-02 3,125 .26195F-02 1.798 -. 08893E-02 1,917 -,46970E-02 5 917 -. 41756E-02 4.217 471571-72 LOAD COND. .. 109124-09 100.000 527061-09 100.000 .41919E-02 -, 47557E-09 -. 46970t -02 5,747 100,000 1,825 469705-02 1,003 -. 13359E-08 100.000 -. 409704-02 1.825 .46970F-02 1,003

-.58270:-09 190.000

COMMUNITE STRATUS 4FFERENCED TO STRUCTURAL AXIS
FOR = -.10912F-09 FOR = 73206-00 FFER = .93939E-02

-, 91919E-05

```
MEMHRANE STRESSES IN COMPOSITE
                    $1644-Y
.34593F.05 0.25945E+05
.25945F.05 -,25945E+05
.25945F.05 17290E+05
      LOAD COND.
                                                 TAULTY
                                              17296E+05
                                                 . $4593E+05
                COMPOSITE MEMBRANE STIFFNESSES
                  ACTUAL
                                REGUIREN
                  VALUE
                                 VALUE
                 .58090F+07
                               .50000F+0b
                .38556E+07
          122
                .21290F+07
                                             100,00
           COLFICIENTS OF STORESS-STRAIN RELATIONSHIPS
                   RELATED TO STRUCTURAL ANES
         .10048E.08 (1) = .33908E.07 (1) = .40600E.03
(2) = .66689E.07 (2) = .18925E.00
           SYMMETRIC
                                              Cao = .56825E+07
           COEFICIENTS OF STRAINGSTRESS RELATIONSHIPS
                   RELATED TO STRUCTURAL AXES
        12014t-06 01 = -.61086t-07
                                              016 = -.31545E-14
026 = .93100E-14
           SYMMETRIC
                                              966 # .27150E-06
         FY .
                                              Gry # . 16825E+07
NUXY B
```

Figure 5.- Concluded.

-.54587E +0≥

4,175

```
DESIGN
                                                                                                                                          DESIGN AND/OR ANALYSIS RESULTS
                                 413
                                                                                                                          0, 30, -30, 60, -60, 90 GRAPHITE EPOXY COMPOSITE - EX. 3
                    SYMPSTRYC COPPOSITE PANEL
                                                                                                                                                  PLY INFORMATION
  n, 3n, -3n, 60, -6n, on GHAPHITE EPORY COMPUSITE - EX. 5
                                                                                                                                                                   PERCENT
                                                                                                                                          NO.
                                                                                                                                                   THICKNESS
                                                                                                                                                   .11368E+00
                                                                                                                                                                     21,35
                                                                                                                                                   .91215E-01
                VO. OF DAN COMPITIONS E
                                                                                                                                                   11328E+00
                                                                                                                                                                     21,28
                                                                                                                                                   .11328E+00
                                                                                                                                                                     85,15
                                                                                                                                                   97205t-02
                                                                                                                                                                     1,85
              PLY PHOPFATTES . ALL PLYS IDENTICAL LONGITION ON MODULUS . .21000F+08 TRA-SVENCE HODINUS . 17000E+07
                                                                                                                                                   ......
                                                                                                                                                                  ........
                                                                                                                                   THICKNESS = . 43239E+00
                                                                                                                                                                   100.00
               SHEAH MINITURE = .05000±+00
POISSON'S PATIO, L=T = .21000±+00
POISSON'S PATIO, T=L = .17000±-01
                                                                                                                                                    PLY STRAINS
                                                                                                                                               S'F. E SAFETY FACTOR
 PLY THIRAMESSES, OPIGHTATIONS, AND DESIGN VAHIABLE NUMBERS
PLY "O. THICKNESS THETA DES, VAH. NO.
                                                                                                                                                    E LONGITUNINAL STRAIN
                                                                                                                                               EPT . TRANSVERSE STRAIN
                    .10000F .00
                                       0.00
                                                                                                                                               FPLT & SHEAR STRAIN
                                      30,00
                    .100n0r.00
                                     -30.00
                                                                                                                                                   LOAD COND.
                    .10CnnF.00
                                     -60.00
                                                                                                              PLY NO.
                                                                                                                             FPI.
                                                                                                                                          5.F.
1.977
3.094
                                                                                                                                                                     5.F.
                                                                                                                                                    -,19309E-02
                    .10000F.00
                                                                                                                          453196-02
                                                                                                                                                                               -.19195E-10 100.000
-.54255E-02 3,391
                                                                                                                                                    -. 3646RF-03
                                                                                                                          27677# -02
                                                                                                                                                                     48,262
                                                                                                                           276776-02
                                                                                                                                          3.096
                                                                                                                                                    .36468E-03
                                                                                                                                                                     48,262
                                                                                                                                                                                 ,54255E=02
                                                                                                                                                                                                 5,591
                          PLY STRATH LIMITS
                                                                                                                         -. 36468r - 03
                                                                                                                                         23,500
                                                                                                                                                                      1.702
                                                                                                                                                                               .,54255E-02
                                                                                                                                                                                                 3,391
THANSVERSE STHATMARE. - . 1/ACCE-01 .AND.LE.
SHESO STRATMARE. - . 18400E-01 .AND.LE.
                                                          .85700E+02
                                                                                                                        -. 56968F-03
                                                                                                                                         23,500
                                                                                                                                                      .27677E-02
                                                                                                                                                                                 542558-02
                                                          .47100E+02
                                                                                                                         -. 19300r-02
                                                                                                                                          4,438
                                                                                                                                                      433396-02
                                                                                                                                                                      1.087
                                                                                                                                                                                 .122601-08 100.000
                                                          .18400t -01
                                                                                                              COMPOSITE STRAINS REFERENCED TO ETRUCTURAL AXIS
                                                                                                                      .45339F-n2 EPY = -19109E-02 FPXY = -.19145E-10
                          STIFFUESS LIMITS
                        4:1.ct. .5000ct.06
                                                                                                                                                  FPT COND.
                       452.CF. 0.
                                                                                                                                                                     5.F.
2.903
3.868
                                                                                                              PLY NO.
                                                                                                                             FPI
                                                                                                                                          1,824
                                                                                                                                                                                                S.+.
                                                                                                                           46986F-02
                                                                                                                                                    -. 606531-02
                                                                                                                                                                                 .27193E=02
                                                                                                                          .51856F-02
.83061F-03
                                                                                                                                                    45503E-02
21953F-02
83062F-03
                                                                                                                                                                               -,79804E=02
                                                                                                                                                                                                 2,311
                                LOADS
                                                                                                                                          10.318
                                                                                                                                                                      8.017
                                                                                                                                                                                .106B0E =01
  (DAD CO 40.
                                                      *** Y
                                                                                                                        -,21953r-02
                                                                                                                                          1,583
                                                                                                                                                                               -,10680F-01
                                                                                                                                                                                                 1.725
                   .20000f .n5 -n.
                                                                                                                        a,45503pa02
                                                                                                                                                     .31856E=02
                                                                                                                                                                      1.479
                                                                                                                                                                                 . 19604E-02
                   .1500nt .n5 -.150n0F+05
                                                    .50000E+04
                                                                                                                         -,60633F-02
                                                                                                                                          1,413
                                                                                                                                                     46986E-02
                                                                                                                                                                      500,1
                                                                                                                                                                               -,27195E-02
                                                                                                                                                                                                 6,766
                                                    .10009E+05
                  -. 1500pF . n5
                                  .10000E+05
                                                                                                              COMPOSITE STHAIRS "EFFRENCED TO STRUCTURAL AXIS
EPX = _46986F-0" EPY = _600435F-02 FPXY = _27195E-02
                                                     .20000E+05
                                                                                                                                                   LAAD COND.
                                                                                                              PI Y NO.
                                                                                                                                                                     S.F.
                                                                                                                                                                                                 5,363
1,788
3,794
5,794
                                                                                                                                         2,033
26,423
1,950
                                                                                                                        -,42159r-02
.32433r-03
                                                                                                                                                      .45249E-02
                                                                                                                                                                     1.041
                                                                                                                                                                                 .54386E=02
                                                                                                                                                    .. 15298E-04 100.000
                                                                                                                                                                                 10289E+01
                                                                                                                                                                               .,48504E-02
                                                                                                                        .. 43857F-02
                                                                                                                                                    ...41857E-02
                                                                                                                                                                     1,003
                                                                                                                                                                                .48504E+02
                                                                                                                          .46947F=02
                                                                                                                                                                     4,013
                                                                                                                                          1.825
                                                                                                                                                    . 32433F.03
                                                                                                                                                                                                 1,788
                                                                                                                         -.15297F-04 100.000
                                                                                                                                                                    14,522
                                                                                                                                                                               -,10289E-01
```

Figure 6.- (0, ±30, ±60, 90) Graphite epoxy composite - Example 3.

.85249F .02

1.894

-. 42159E-02

```
44
```

```
COMPOSITE STRAITS REFERENCED TO STRUCTURAL AXIS
FPX = -. 47159F-02 EPY = .44249F-02 FPXY = .54506L-02
                                    I NAD COND.
PI v Not.
              FPI
                                        FPT
          -.19195F-10 100.000
.47100F-02 1.820
                                       .00884E-10 100.000
                                                                  ,10877E-01
                                      -. 47100E-02
                                                     5.737
                                                                  .54586E=02
                                                                                   3,385
          -,47100r-02 1.820
-,47100r-02 1.820
-,47100r-02 1.820
-,98074r-09 100.000
          -, 47100F-02
                                      47100E-02
                                                       1,000
                                                                                   5,303
                                                       3.757
                                                                 -,54387t-02
                                                                                   3,585
                                                                 -, >4387E=02
                                       .47100F-02 1,000
.10284F-08 103,000
                                                                                   3,303
                                                                 -,10877F-01
COMPOSITE STHAINS REFERENCED TO STRUCTURAL AXIS
FOR # -.191956-10 FOY # 'bonnage-in Fory # ,1087/E-01
                       #EMMRANE STURSSES IN COMPOSITE

SICHARY SIGNARY TAURXY

.375,75.05 0. 0. 0. 0. 4591/L+04

.28175F.05 -28175F.05 18783E.05 18783E.05
           LOAD CONC.
                        PHPASITE MENANAME STIFFNESSES
                          ACTUAL
                                         REGUIREN
                          VAL IIF
                       .53648F .07 ..
                                        .50000F+nn
                                                         100,00
                       .18587E+07 0.
                                                         100.00
                 COFFICTENTS OF STRESS-STHAIN RELATIONSHIPS
                           STEATER TO STRUCTURAL AXES
     #FLATER IN STRUCTURAL ARES

Cit = .10077E-04 Clp = .31620E-07 Clb = .84078E-04

C22 = .70071E-07 C20 = .3445E-01

Symmetrate Cnb = .34557E+07
```

Figure 6.- Concluded.

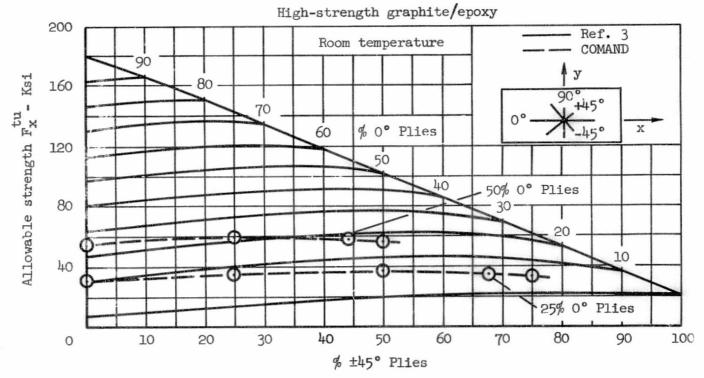


Figure 7.- Ultimate tensile strength  $F_x^{tu}$  high-strength graphite/epoxy -  $\left[0_{i}/\pm45_{j}/90_{k}\right]^{x}$  family.

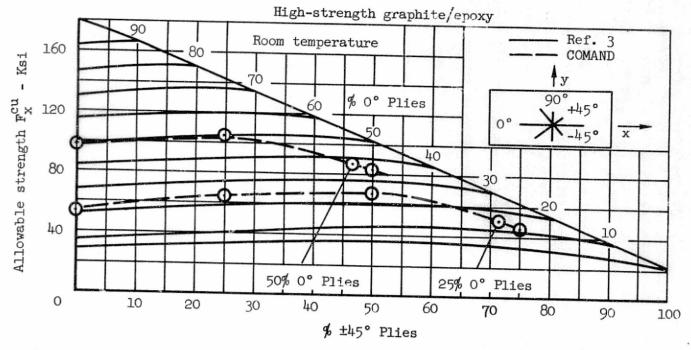


Figure 8.- Ultimate compressive strength  $F_X^{cu}$  high-strength graphite/epoxy -  $\left[0_{i}/\pm45_{j}/90_{k}\right]$  family.

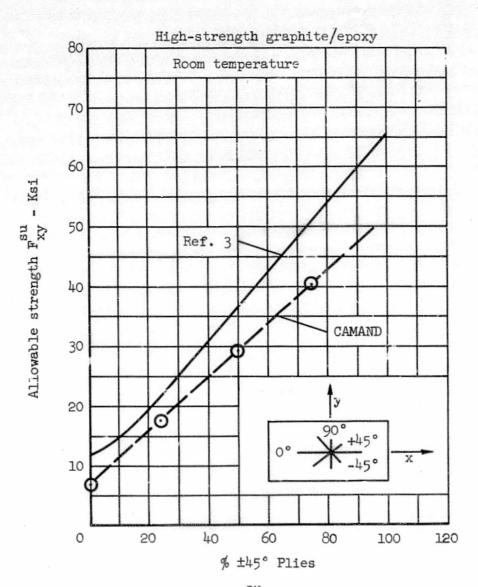


Figure 9.- Ultimate shear strength  $F_{xy}^{su}$  high-strength graphite/epoxy -  $\left[0_i/\pm45_j/90_k\right]$  family.

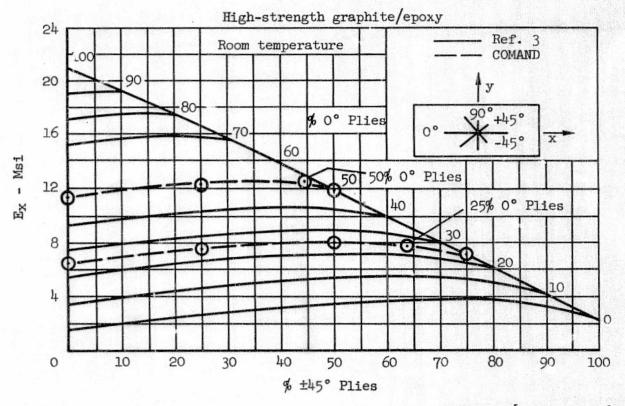


Figure 10.- Extensional modulus  $E_{\rm X}$  high-strength graphite/epoxy -  $\left[0_{\rm i}/\pm45_{\rm j}/90_{\rm k}\right]$  family.

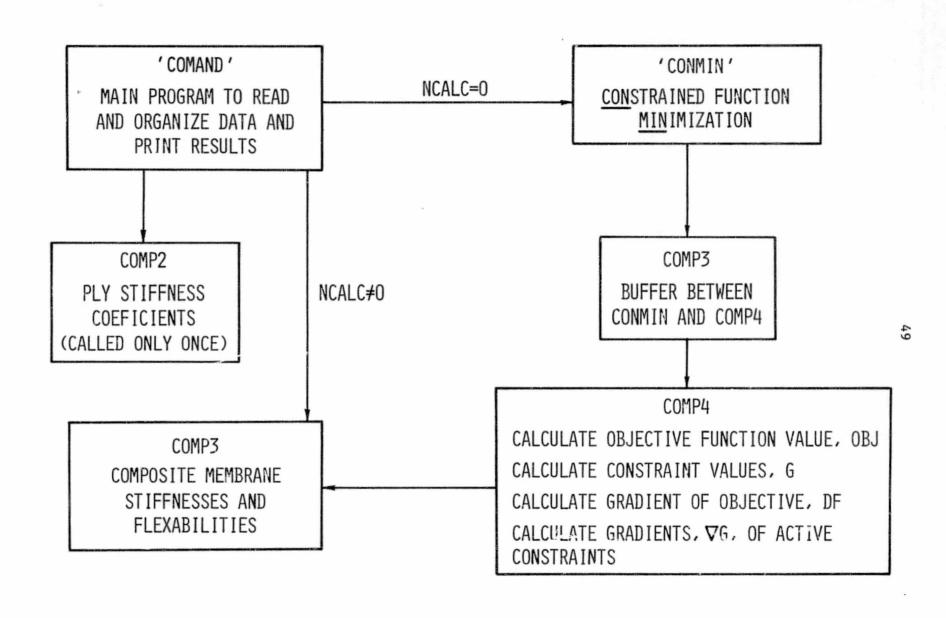


FIGURE 11.- 'COMAND' BLOCK DIAGRAM.